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PERFORMANCE ANALYSIS OF COFIRING DENSIFIED REFUSE DERIVED FUEL IN A MILITARY BOILER

RYCON INCORPORATED / CINCINNATI, OHIO 45229

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DECEMBER 1981

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This report provides an overview of existing densified refuse-derived fuel (dRDF) receiving, storage, handling and combustion equipment at Wright-Patterson Air Force Base. dRDF is being burned as part of a long term alternative fuel evaluation program to develop design and procurement criteria for multiple fuel boilers. Recommendations are offered for specific equipment, procedural changes, and studies to improve the efficacy of the present configurations of dRDF as a fuel. A discussion of the fuel use criteria is presented. The options for continuing the present dRDF supply

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) arrangement vs. the feasibility of local production of dRDF are presented. Research needs are summarized. A preemptive, integrated local synthetic solid fuel production facility and boiler performance test is recommended as a continuation of the program.

PREFACE

This report was prepared by Rycon Incorporated, 690 Clinton Springs Avenue, Cincinnati, Ohio 45229, under contract No. USAF MIPR N-80-50 with the Air Force Engineering and Services Center, HQ AFESC/RDVA, Tyndall AFB, Fl 32403.

This report covers the period beginning August 1980 and ending Sept 1981.

Steve Hathaway, Project Director, HQ Air Force Engineering and Services Center, Tyndall AFB, Florida, has provided expert direction and criticism in technical and programmatic areas. Tom Shoup, Chief Environmental Planning Section, 2750 ABW/DEEX, acted as principal coordination point with Wright-Patterson Air Force Base to provide useful comment and data. Don Walter and Leon Lehr of the U.S. Department of Energy provided valuable support and extensive data. The operating personnel, foremen and supervisors of Building 1240, WPAFB, cooperated fully and provided much useful information. Appreciation is expressed to Carlton Wiles of the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and Paul Farber, Argonne National Laboratory, for their expert advice and technical assistance.

This report has been reviewed by the Public Affairs Office and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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SUMMARY

Densified Refuse-Derived Fuel (dRDF) is manufactured by extracting a fraction of urban wastes or refuse that possesses the majority of the fuel value to be found in this raw material. This beneficiated fraction is densified or compressed into small dense pellets for the purpose of substituting them for coal which is used to produce steam in spreader stoker boilers. The U.S. Air Force is conducting a multi-year evaluation of merits and problems resulting from the use of this renewable, alternative fuel resource. This report examines a number of facets of the evaluative program and offers recommendations for improving the utility and value of this fuel resource for military and civilian purposes.

The technologies that have been used to manufacture dRDF have been reviewed both to report their experiences and to examine possible ways in which the manufacturing process may be improved. Specific technical and economic concerns associated with the manufacturing process have been discussed.

Past and present experiences with the handling and firing characteristics of dRDF at Wright-Patterson Air Force Base and in other locations have been reviewed and discussed. Recommendations are offered for improving specific troublesome attributes of the current supply of dRDF.

One requirement for more effective and less costly use of dRDF by Wright-Patterson Air Force Base is the development of a local fuel manufacturing capability. Options for achieving this goal are discussed and the optimum approach for achieving both Air Force goals and local community waste disposal requirements is recommended.

A number of specific research needs and programs are introduced as Research Briefs. Program costs and desired results are estimated. Areas considered include both improvements of the characteristics and utility of the existing dRDF formulation, as well as the advantages promised by a substantially different formulation. The most pertinent literature concerning experience with dRDF is presented in a series of briefs which stress both useful results and weaknesses in terms of the Air Force evaluation. Several literature briefs are included to provide technical support to principal recommendations and to emphasize specific research needs.

The principal recommendations of the report are:

1. To achieve maximum cost savings in the shortest possible time,

an integrated test of a local fuel formulation production facility and an Air Force boiler must be conducted.

2. The local fuel formulation and production facility should be privately owned. Existing dRDF formulations should be revised to include coal, beneficiated urban wastes, and other under-utilized fuel resources. The management of the local fuel production facility must have a vested interest in actively supporting additional evaluations of various dRDF formulations to achieve the production of a premium spreader stoker boiler fuel. (Fuel use criteria are presented in the report to provide initial direction for this effort.)

3. The Air Force should automate control and operation of one boiler so that minimum time and expense will be incurred in evaluating various fuel formulas. This same instrumentation may be used to assure optimum operation and minimum fuel use by all boilers supporting the base.

4. Given existing financial circumstances, cost sharing is most likely to be achieved with a private company. Air Force funds for the long term procurement of fuel may be used as the incentive for cost sharing the evaluative process.

5. The system that seems most successful at producing a beneficiated refuse-derived fuel of a quality suitable for dRDF formulation is owned and operated by the City of Ames, Iowa.

These recommendations, while more extensive than anticipated, have been carefully considered by the author after weighing a large number of factors. They are believed to offer the lowest cost, lowest risk, shortest term approach to reducing the cost of steam production through the use of alternative refuse-derived fuels at all U.S. Air Force Bases.

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SECTION I

INTRODUCTION

This report presents a management and technical overview of long term tests and evaluations of densified refuse-derived fuel (dRDF) as a spreader stoker boiler fuel. The tests are being directed by the United States Air Force at Wright-Patterson Air Force Base in Dayton, Ohio. Many aspects of dRDF production and use, both directly associated with this project and through work conducted by other private and public groups, are examined from several points of view.

The primary purpose of this report is to integrate the information developed by others and the information being developed in this series of tests into the most beneficial and overall cost effective "next step" in increasing the utility of dRDF, both to the United States Air Force in terms of a routine facility mission support capability and facility energy security and independence during periods of domestic or international strife, and to increasing the use of domestically produced, renewable energy resources throughout our nation.

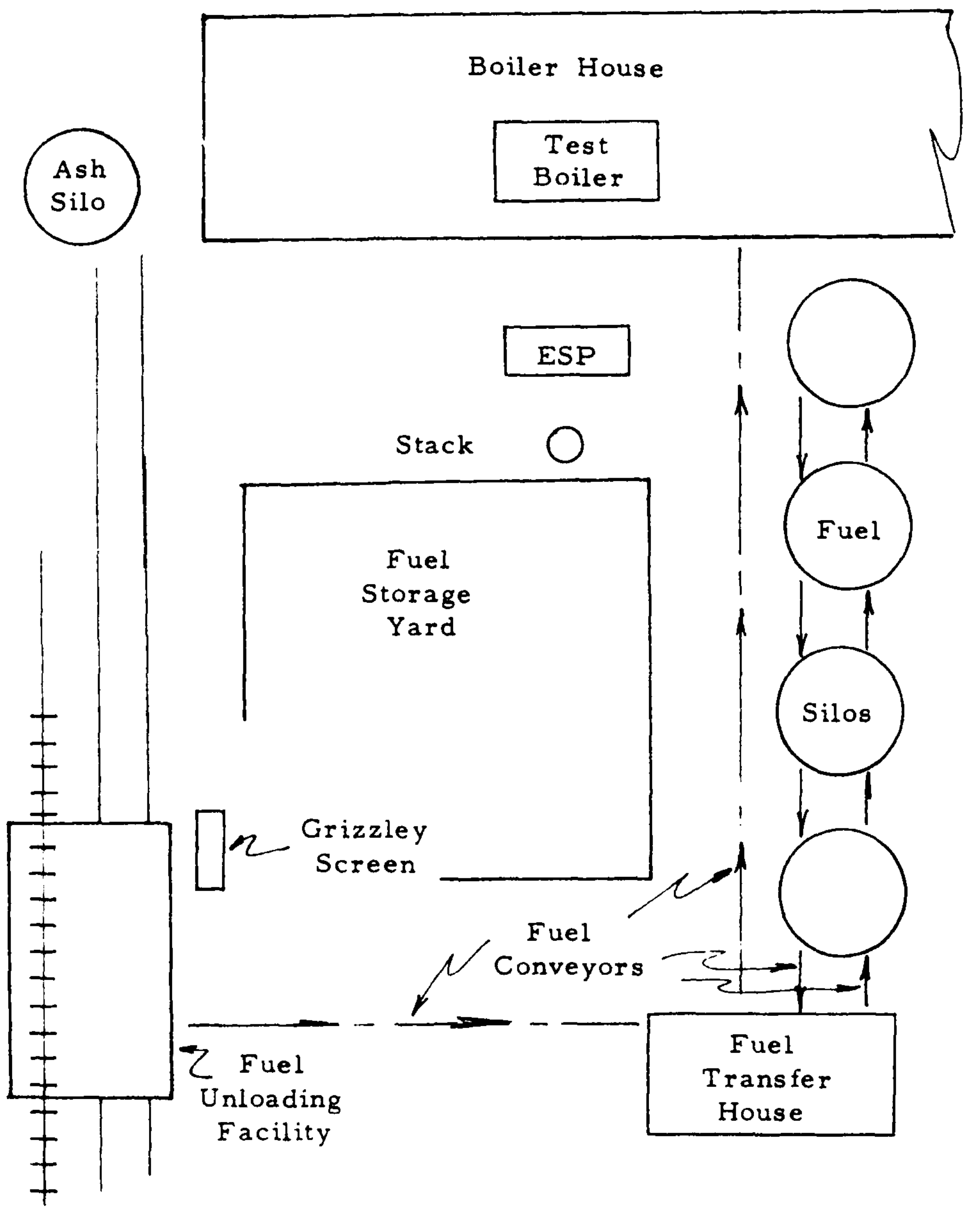

Figure 1. Sketch of Bldg. 1240 Facilities (Not to Scale).

SECTION II

DESCRIPTION OF FUEL RECEIVING, STORAGE, HANDLING AND FIRING FACILITIES AT WRIGHT-PATTERSON AIR FORCE BASE BUILDING 1240

Fuel is delivered to Building 1240 at Wright-Patterson AFB in either of two ways (Figure 1). First, it may be delivered in conventional coal hopper cars and, second, by any size truck. A coal unloading facility is provided. Rail cars are received and unloaded in one bay of the facility and trucks are received and unloaded in the other. The rail car unloading facility is of conventional design with a high ceiling, suspended car shaker, rollup doors on either end and sufficient length to accommodate two hopper cars simultaneously. Underneath the tracks are grizzley type screens with approximately 6 in. openings and steep sided hoppers (i.e., 80 degree slopes or better) which conduct fuel to belt conveyors that remove the fuel from the unloading facility. The truck side of the facility is similar to the rail side but lacks rail tracks. Duplicate grizzleys and hoppers allow for the unloading of two dumptrucks simultaneously and rollup doors can be used to weatherproof the unloading operation.

A concrete-floored fuel storage yard is provided to augment fuel storage silos. The yard is surrounded by approximately a four foot high concrete retaining wall with openings on one side only for the ingress and egress of trucks, as well as the removal of coal by front end loader or bulldozer from the fuel piles. The fuel storage area is unprotected from the weather. Fuel is removed from the yard by transporting it a few yards to a grizzley screen and hopper located outside, adjacent to the truck and rail car unloading facility. Fuel may be delivered to the storage yard only by truck.

Fuel, unloaded either from rail car or truck in the receiving facility or removed from the storage yard, is conveyed by belt conveyors to one of four fuel storage silos. Fuel, added to the silo from the top, freefalls to the fuel surface and is removed at the base of the silo. The silos are approximately 30 feet in diameter and 70 feet in height. Fuel is unloaded onto a single horizontal conveyor located beneath each silo; this conveyor serves all silos. Thus, blending of fuels from one or more silos is possible. The storage silos have conical bottoms and high strength vibrators for vibrating the conical bottom of the hopper to facilitate unloading.

Fuel is conveyed out of the silo area to the base of an incline conveyor, which raises it above the level of the bunkers serving the boilers in the boiler house. The fuel bunkers are of older, rounded bottom design. Fuel is removed from one of a number of slide gate controlled outlets, aggregated on horizontal conveyors, and delivered to a tipping bucket which controls the conveyor operation. The tipping bucket then delivers charges of coal of pre-selected weights to a non-segregating distribution chute and thence into the spreader mechanism attached to the furnace and boiler.

The spreaders are conventional Detroit overthrow type and the furnace is served by a Detroit rotograte traveling grate. The boiler is designed to produce high temperature hot water with water leaving the boiler at approximately 450° F and sufficient pressure to maintain liquid state. Due to changes in the distribution system, water is returned to the boiler at approximately 350°. Bottom ash is collected by pneumatic system and delivered to an ash silo. Fly ash is collected from the base of electrostatic precipitators and normally is delivered to the same ash silo. Ash is removed from the ash silo by dumptruck. The silo is equipped with water sprays for suppressing dust when ash is being unloaded into the truck.

The boiler used for testing dRDF was built in the 1950's by B&W and, due to modifications in the steam and hot water distribution systems, it is used primarily as a supplement to newer boilers built by Combustion Equipment Associates. dRDF is fired only in the older boiler.

SECTION III

MODIFICATION OF FUEL RECEIVING, STORAGE, HANDLING AND FIRING SYSTEMS TO ACCOMMODATE dRDF

The basic system for handling coal has been used for handling dRDF and a few operational procedures have been modified in order to accommodate the dRDF fuel. In general, capital expenditures on additional equipment for management of dRDF at the site have been minimal. The single exception of this might be the heavy duty vibrator attached to the silo used for storing dRDF. Such equipment is desirable for coal removal from silos, especially during periods of inclement weather when the coal may be received wet. Vibrators are attached to each of the silos at Building 1240.

Operation of the fuel unloading facility and silos is controlled by a computer. Deviations from anticipated normal operation are extremely difficult to accomplish due to the limited capabilities of the existing operational control program. For example, fuel cannot be removed from the silo and transferred to the storage yard, even though the mechanical capability exists for this operation. Consequently, a more versatile program is required or, more desirably, a complete central manual control board with override capability is needed.

A single belt conveyor is used to move fuel through the facility. If an unanticipated break occurs, the facility steaming capabilities could be lost. One remedy is to supply replicate conveyor system; however, in view of the ease with which belt conveyors may be spliced and the ready availability of replacement belts in the Dayton area, a replicate conveyor system is not recommended.

A number of problems in dealing with dRDF as a boiler fuel have been encountered. Some are unique to the system, but most are unique to the type of fuel.

Several experiments have been run in attempting to receive dRDF by rail from the supplier, the Maryland Environmental Service. Each of these experiments, one of which took place during the period of this contract, has produced less than satisfactory results. The dRDF generally bridges in the hopper car in such a way as to require several manhours to assist in the unloading of the car. Settlement was on the order of 15% to 25% with the creation of numerous fines because of the jostling and abrasion of the material in the car. Substantial quantities of dust are released during the car unloading. Although the same [illegible] encountered for coal, coal generally does not require manpower for rail car unloading; hence, the crew is not exposed to the high concentrations of dust. Dust protection masks are available and are provided to crews when they unload dRDF. The nuisance of having to assign four men to a rail carload of dRDF for unloading purposes cannot be discounted.

The bulk of dRDF used by the facility has been delivered by truck from Maryland. The fuel has generally arrived in good condition. Tarpaulins are used to protect the fuel from the weather and the trip is generally brief, a matter of a few days at most. Unloading is easily facilitated because the lift bodies on the trucks allow the dRDF to slide from the truck by gravity. Unloading inside the coal unloading facility creates considerable dust, but a crew is not required during the unloading process. Alternatively, the fuel may be delivered direct to the coal yard if insufficient storage is available elsewhere.

Storage of dRDF at the facility has proved to be the area of greatest difficulty. Several storage alternatives were explored, because the fuel does not withstand exposed outdoor storage well. One problem was outdoor storage, with a resulting deterioration in fuel quality due to moisture absorption. dRDF, when stored in piles out-of-doors, tends to form a crust over the surface approximately six inches deep. This crust tends to shed rainfall and preserves the remainder of the pile in a dry condition. This phenomena is totally dependent on the area of the pile being extremely well drained (i.e., runoff moves away from the pile, not underneath the pile). Outdoor storage of dRDF was practiced successfully, although the dust and fine content of the fuel was predictably increased due to deterioration of a substantial portion of the pile (i.e., weathering).

A storage silo was designated and set aside for exclusive storage of dRDF. It was found, however, that the dRDF had a bearing capacity prior to deformation of not more than 285 pounds per square foot. Thus, only a pile roughly 20 feet deep could be stored without bridging and jamming the unloading chute. Therefore, the majority of the silo could not be used for fuel storage. Consequently, the silo was predominantly used as a fuel staging area for blending and delivery to the bunkers supplying the boiler with fuel. Dust and spillage during silo unloading operations was severe, but personnel were not required to be present.

Fuel storage silos normally discharge materials from the top of the silo first. This is accomplished by the formation of a moving column of fuel approximately the size of the opening (two to four square feet) at the base of the silo, which extends to the surface of the fuel stored in the silo. Frictional forces are least on the surface fuel particle, so a cone shaped depression is formed in the surface of the fuel and supplies fuel to the moving column. Thus, the first fuel added to the silo is the last to be removed.

Unloading of conveyors into the storage bunkers above the boilers did create substantial amounts of dust and at least one man was required to be on the site to supervise the filling of the bunkers. Dusting in this area was extreme to the point where a potential fire and explosion hazard could conceivably be created.

Additionally, removal of the dRDF alone from the fuel bunkers has proved slightly more difficult than coal alone. When firing fuel mixtures (50% by volume dRDF and 50% coal), unloading of the bunkers has not proved to be a problem. However, when 100% dRDF firing was attempted, unloading of the bunkers was decidedly more difficult (i.e., jams required manual rodding to move the fuel). On balance, while jams do occur with coal (especially during periods of inclement weather or with inferior grades of coal), the dRDF may be considered more difficult to handle in conventional coal storage bunkers, requiring additional operating personnel. Additional dust control equipment is probably required in the area of the bunkers, if the current dRDF formulation is to be burned as a normal operation.

The boiler, which was used to test both blended dRDF and coal and dRDF alone, was designed to produce approximately a hundred million BTU's per hour of heat. In actual operation, due to changes in hot water usage, a maximum of about 62 to 65 million BTU's per hour could be attained and normal operations ran 32 to 37 million BTU's per hour. Thus, the impact of dRDF alone on boiler capacity could not be evaluated. Additional testing at a boiler normally operated at design loading is recommended in order to investigate this particular question.

In monitoring the blend tests, minimal clinkering was observed and could at worst be compared with the operational impacts of off-spec coal or with lumps of non-fuel material in coal. In every case, the clinkers were easy to break up by rodding, which is a normal part of the boiler operator's duties. When firing dRDF alone, clinkering was observed and (in one instance) was relatively extensive along the right side of the boiler. However, as pointed out in a monthly status report, dRDF is extremely sensitive to spreader adjustment. Apparently a worn shaft in the spreader resulted in a slight malalignment. This tended to cause the fuel to bulk against the right wall as opposed to getting even distribution on the fuel bed. The bulking in turn reduced air flow through the right [illegible] the grate and created a reducing environment in the fuel bed, which enhanced the opportunity for clinker formation. During one of the tests, the worn shaft became noisy (obviously defective) and was replaced. On replacement, the apparent clinkering problem disappeared. Hence, clinker formation and fuel bed management in the boiler (when firing any mix of coal and dRDF) is within the range of normal boiler operating practice.

Emissions data from the boiler test is not available to this contractor as of the writing of this report. However, visual observations of on-line monitoring instruments indicate that sulfur oxides were depressed (as expected), fuel burn-out was as good or better than with coal alone, and particulate emissions (especially due to the low loading of the boiler) were well within what might be considered a normal range for the boiler.

Ash formation and management is another area of concern. dRDF produces roughly twice as much ash per ton as the coal fired at the facility. Coal is normally 7% to 9% ash and the dRDF averages at least 15% ash content. Selecting the rather arbitrary figure of $3 per ton for ash disposal costs, the cost of ash disposal on a ton of coal is roughly 22 1/2¢. dRDF, having a higher ash content, costs about 45¢ per ton; but, since two tons of dRDF are required to replace one ton of coal, the actual cost on an equivalent heating value basis is 90¢ per equivalent ton of coal. Ash characteristics were compatible for the existing pneumatic system. The clinkers that formed were soft and easily broken apart. For the most part, the ash was relatively fine granular material completely compatible with the pneumatic handling system. A high load on the boiler might exacerbate the ash management problem; however, this condition has not as yet been tested.

SECTION IV

SUMMATION OF CAPITAL EQUIPMENT AND OPERATIONAL PROCEDURE CHANGES

Single purpose capital equipment changes have been minimal to accommodate dRDF. The principal expenditure might be considered to be the vibrator attached to the conical base of the silo designated for dRDF storage. [illegible] both silo and vibrator are identical to those used exclusively for coal. The silo, due to the low load bearing strength of the dRDF, cannot be economically used with or without a vibrator because of the deformation and the packing of the dRDF in the silo when loaded to depths of more than about 20 feet. Hence, alternative means were found for storing dRDF. One which was practiced during several of the tests, was the temporary assignment of the truck unloading area of the receiving facility for indoor dRDF storage. In this area, about 100 tons of dRDF could be stored, withdrawn and delivered to the silo, and again withdrawn for delivery to the boiler fuel bunkers. The second expedient practiced at Building 1240 was the use of a portion of the existing coal storage [illegible] stockpiling dRDF. [illegible] three hundred tons of dRDF were stored in this manner for boiler performance tests.

Two alternatives are available for improving current dRDF storing practices. The first is to modify the silo by installing several false bottoms so that each bottom carries approximately a maximum depth of 20 feet of dRDF. The silo could then be almost completely filled with dRDF and the compartments in the silo loaded and unloaded successively. The capital cost of this modification would probably be great due to the difficulty of retrofitting the silo with the false bottoms, hopper doors, controls, vibrators, and level monitoring devices.

A second option for dealing with the problem of dRDF storage is the construction of a shed over a portion of the coal storage yard to prevent major adverse impact of inclement weather on stored dRDF. Such a shed need consist of little more than structural supports and a roof sufficiently high to allow front end loaders to operate and trucks to unload directly into the shed. The cost of such a shed is measured in the tens of thousands of dollars. From the shed, dRDF could be transported directly into the bunkers for burning or into the silo for blending with coal. An additional benefit to the use of storage sheds is the biodrying of the dRDF.

Another area of concern is dust control for the dust associated with dRDF. As indicated earlier, dust during rail car unloading was severe and a crew was required to participate in the unloading. The problem is [illegible] unloading. [illegible] dusting in the area of the fuel bunker serving the boiler, however, is severe. Due to jamming and normal unloading procedures, a person is required to be in attendance when the fuel is being handled. In addition, dust accumulation adjacent to the bunkers indicates a potential for either spontaneous combustion or flash fire due to accidental ignition. Hence, additional dust control is desirable.

Three basic approaches appear to be suitable. The first of these is to install powered ventilation which removes the dust from the bunker area and distributes it into the boiler overfire air system or to a baghouse. This option appears to be extremely costly both in capital and operating costs.

The second option is the mist oiling of the dRDF at such a time as it is removed from the storage silo either for blending purposes or for transmittal to the bunkers for dRDF alone firing. No data is available on the effect of oil sprays in suppressing dRDF dusts. However, one might surmise that the cellulosic and fibrous nature of the dRDF dusts would tend to make them agglomerate to and be wetted by oil droplets, which, in turn, would make them adhere to larger particles. Fuel jamming in the bunker might be exacerbated by the oiling, since a sticky surface would be created on both the pellets and the smaller particles.

The third technique which might allay the dust problem during transfers is steam or water sprays applied in lieu of oil. The principal advantage is the lower cost of the additive, but every pound of water added to allay dust must be economically offset by a loss of fuel to the boiler and potential loss of peak capacity. Under low load conditions, this might be the most cost effective retrofit technique for dealing with the problem.

Removing dRDF from the boiler supply bunkers (as indicated earlier) has also been an occasional, but recurrent, problem. Although not severe, removal of the dRDF has required more than a normal amount of operating manpower when dRDF alone is to be fired. If the boiler is to be committed to dRDF firing, additional equipment for use with the bunker is desirable. Three options appear to be useful. The first option is the addition of more vibrators or mechanical wrappers to the bunker. The second option is to locate one or more air blasters or air cannons near the base of the bunker which shocks, lifts and lubricates the fuel, causing flow to begin. The third option is to modify the shape of the bunker by inserting steel plates to create steep sides as opposed to the existing rounded ones. The reduction in bunker size would increase the manhours required for filling the bunker, because its storage capacity would be proportionately less than is presently available. The continuous firing of dRDF alone as a normal operating procedure does not seem warranted, since blended fuel accomplishes many of the desired results from dRDF. Hence, modification of the hopper is not a primary need at the present time. Further exploration of the effects of blends on the hopper discharge function might be desirable.

A different and preemptive approach to the resolution of the problems described in the preceding paragraphs of this section is available and deserves serious consideration. Each of the problems described heretofore is a function of one or more properties of dRDF as presently formulated. All of the facility retrofit solutions proposed for each problem could be preempted by modifying the dRDF formulation technique and thus improving defined undesirable properties. As this formula modification approach appears to offer the greatest overall cost-benefit while not adversely affecting the desirable properties of dRDF, it is the recommended approach, even though its development requires greater effort and slightly more time than the suggested tack-on solutions.

SECTION V

USE CRITERIA FOR EVALUATION OF dRDF PROPERTIES

This section represents a considerable amount of deductive and inductive logic, informed opinion and speculation. This section does begin to give structure and direction to considerations for future dRDF formulation, testing and preferred results.

Philosophically, in evaluating dRDF as a manufactured or solid synthetic boiler fuel, it would appear most desirable to make the best fuel possible and then to optimize boiler operations against the most desirable characteristics of that fuel. Thus, an integrated fully optimized system for the production of steam, hot water or electric power should result for any specific existing or proposed facility. To date, efforts to manufacture solid fuels have been extremely limited in scope. dRDF has been more or less single purpose in scope, that is, to turn garbage into a fuel minimally acceptable to stoker fired boiler owners and operators. If one accepts the premise that a certain level of cost must be incurred in manufacturing any quality of a solid fuel (assuming raw materials are economically comparable), then it would seem logical to manufacture a fuel that provides for the greatest amount of reduction in other costs associated with the operation of a boiler. Thus, on a relative basis, the goals of the boiler operator can more nearly be met by a manufactured fuel rather than a mined or unimproved fuel.

Basically, these goals may be summarized as being able to purchase a less expensive fuel than that currently being used. Cost savings may be achieved through a lower purchase price, reduced on-site fuel processing cost, reduced emission control costs, increased steam production capacity, or a combination of these factors. Given these general goals of the boiler operator, the fuel manufacturer must consider a number of criteria in formulating a premium synthetic solid fuel. The following criteria are offered for consideration.

STRUCTURAL INTEGRITY

The structural integrity of the synthetic solid fuel is of critical importance. Structural integrity allows the fuel to be handled in typical coal-handling equipment which may exist or may be readily available from manufacturers. The suppression of dust is a desirable goal in the synthetic fuel. Dust lost to the environment represents a health hazard, a potential explosion hazard, a fugitive emission problem and a loss of fuel. In furnaces, it further complicates the combustion of the fuel by increasing loadings of ash on the emission control equipment, as well as increasing the potential for deposition and corrosion of the boiler tubes and increasing the potential for fuel loss due to insufficient combustion time.

STORABILITY

The synthetic fuel should be capable of being stored unprotected out-of-doors with minimal loss in combustion qualities; i.e., it should at least be similar to coal. Even coal degrades in the presence of the oxidizing and weathering forces of the environment when left in piles for an extended period of time. Minimal loss of structural integrity during exposed storage should be achieved by the manufacturing process.

COMPATIBILITY WITH UNMODIFIED COAL-HANDLING EQUIPMENT

Any synthetic solid fuel which is to be marketed must necessarily be compatible with essentially unmodified coal-handling equipment already in service. Manufacturers currently producing coal-handling equipment can reproduce this equipment more quickly and probably at lower cost than they can produce new designs. Hence, the fuel that is manufactured must, for all practical purposes, act like coal in the handling and storage procedures.

COMPRESSIVE STRENGTH

Because coal is often stored in silos and bunkers of considerable depth, a certain minimum compressive strength must be attained by a synthetic fuel. This compressive strength should probably exceed 1,000 pounds per square foot without any deformation or crumbling of the fuel particles.

PARTICLE SIZE RANGE

The particle size range of the synthetic solid fuel is a critical consideration, especially when firing spreader stokers. These stokers incorporate an aerodynamic separation function in order to maintain a uniform level of fire and heat release over the entire surface of the furnace. At the same time, the stokers provide for a uniform burn-out point at the end of the grate to preclude release of burning fuel to the ash handling system with resulting clinkering and failure of the system. A range of particle sizes is extremely desirable so that larger ones are thrown to the back of the boiler and smaller ones fall nearer the front, thus providing for uniform rate of burning and heat release throughout the boiler and a uniform fuel burn-out point.

Because combustion air flows in the furnace and boiler essentially act as particle separation systems, fines should be minimized. Since air moves through the grate, fuel bed and boiler at a nominal velocity and upward direction, any particle with a settling velocity less than the nominal air velocity will not settle on the burning fuel bed, but will be quickly carried through regions where combustion could occur. Thus, unburned fines or carbon loss occurs and boiler efficiency decreases.

HEAT CONTENT

The heat content of a synthetic fuel is of significance. Spreader stokers are generally designed to accommodate certain heat contents of various types of coal. Design firing requirements are met by adding a number of identical spreaders to a given furnace design, depending on the anticipated heat content of the fuel to be burned. When supplementing or supplanting fossil fuels with a synthetic solid fuel, the synthetic must fall within the spreader capacity, including safety factors designed into the normal system; i.e., additional spreaders cannot be easily retrofitted on a furnace. As a result, the heat content of the synthetic fuel should be at least sufficient to operate the boiler at design capacity, while operating only on a synthetic fuel. For comparison, a heat content of 9,500 to 10,000 BTU's per pound synthetic as compared with perhaps 13,000 BTU's per pound coal should be adequate.

BULK DENSITY

In general, the bulk density of the synthetic fuel must approach that of coal as well as match existing feeder capacity. Spreader feeders are basically volumetric devices. They deliver a selected volume of fuel or fuel space per hour regardless of the density of the fuel. If the fuel density decreases sufficiently, it becomes physically impossible to feed adequate fuel into the boiler to maintain desired capacity. Hence, a reasonable estimate might be a bulk density of 70% to 80% that of the original design fuel, coal. The age of the boiler in making this determination is of significance also, because older boilers generally included more liberal safety factors than do newer ones.

SULFUR EMISSIONS

The rate of sulfur oxides emissions produced when firing the synthetic fuel is a principal consideration. If high sulfur coal is burned, then post-combustion sulfur control devices must be added to the system at great cost. A manufactured synthetic solid fuel inherently provides opportunity for suppressing sulfur emissions while preparing the fuel. Thus, in a synthetic fuel, sulfur should be suppressed by processing and appropriate additives to arrange for the desired rate of sulfur emissions from the fuel within optimum economic boundaries (i.e., not fuel sulfur content but fuel sulfur emission rate), must be the controlling specification.

QUALITY CONTROL

A synthetic [illegible] manufactured, should necessarily represent a more uniform fuel than coal procured from several mines or mines [illegible] across several seams. The careful control of quality [illegible] the cost of synthetic fuel, should allow for more [illegible] operation and result in decreased operating costs.

[illegible] AND CORROSION

[illegible] trace materials in coal or solid fuels. The [illegible] at which [illegible] softens or deforms either in [illegible] correlated to these [illegible] for various types of fuel [illegible] temperatures. Hence, depending on [illegible] use of additives to change [illegible] trace materials eutectic [illegible] an important consideration.

[illegible]

[illegible] other [illegible] fuels are de- [illegible] components and fixed carbon components. [illegible] slower to burn and more difficult to ignite; the volatiles are fast burning but do not provide for any duration of heat release in the fuel bed (i.e. too rapid a fuel bed burn-out). [illegible] volatiles and fixed carbon must be [illegible] and complete burn-out of [illegible] the same time maintaining the [illegible] maximum the heat released per [illegible]

[illegible]

[illegible] important consideration in a syn- [illegible] maximum of economically [illegible] to reduce the possibility of clink- [illegible] as well as reduce the possibility of deposits on boiler tubes, superheater tubes, electrostatic precipitators [illegible]

[illegible] must be considered when [illegible] content, the lower the number [illegible] weight of fuel and the greater the expense of removing and discarding the ash. On the other hand, an increase in this area as traded off against higher sulfur content, better combustion characteristics, etc., or lowering of fuel cost could be economically advantageous. Further, the modification of the furnace to achieve higher grate speeds than the original design required is both inexpensive and easy to retrofit on spreader stokers.

GASIFICATION CHARACTERISTICS

The compatibility of a synthetic fuel with close-coupled gasifiers or other types of gasifiers that may be used to supplant oil or gas fired boilers is also of significance. As fossil fuel costs increase, synthetic solid fuels should be capable of supplanting oil and gas on a temporary or permanent basis through the use of close-coupled or free-standing gasifiers. Hence, the gasification characteristics of the fuel are also a criteria consideration.

SECTION VI

[illegible] OF WRIGHT-PATTERSON AIR FORCE BASE PROCEDURES FOR TESTING dRDF

The general [illegible] by Wright-Patterson Air Force Base to evaluate dRDF as a [illegible] potential boiler fuel has been effective. Engineers, facility manager and operating crews have [illegible] most significant test of this potential boiler fuel. As a result of this cooperation, a considerable amount of [illegible] developed.

Improvements [illegible] general area of sophisticated [illegible] instrumentation [illegible] operations. Under the current test program, the boiler has been operated as is normal practice in the facility. The instrumentation supplied with the boiler is adequate to follow load and to give [illegible] of the boiler operating conditions. This instrumentation, while adequate for normal operations, could readily be supplemented by additional instrumentation to allow for [illegible]

In addition, [illegible] the boiler should create additional fuel savings by improving operating efficiency. For example, one type of information [illegible] of the boiler operating efficiency. Boiler operating efficiency is measured by standard ASME techniques used on coal and other fuels while the boiler operates and follows [illegible] controls. An unanswered question [illegible] this approach is the possibility that, after modifying the [illegible] characteristics, the [illegible] could have been operated more [illegible] than the existing [illegible] would allow, especially since those controls were designed and programmed for a fuel of substantially different characteristics than dRDF. Thus, it is possible to compare two fuels in a given boiler only when the boiler operation is separately optimized for each of those fuels.

Typical instrumentation which could be added to the existing test boiler at Wright-Patterson Air Force Base might be represented by fireside temperature and O_2 [illegible] capabilities, as well as temperature monitoring at superheater tubes and at the boiler exits. O_2 scan capabilities should be added above the combustion zone to determine that oxygen levels are [illegible] the furnace. Improved con- [illegible] and overfire sources is extremely important, as well as some knowledge of the leakage into the boiler [illegible] the points at which this occurs. Additionally, [illegible] temperature monitoring capability is [illegible]

To achieve optimum furnace operation, air is supplied to the fuel bed through the grate, first, in sufficient quantities to allow the bed to burn or at least volatilize and, second, to assure that the bed does not reach such temperature that the ash slagging point is approached and extensive clinker formation initiated. Optimal operation of the furnace is approached only when minimal air is supplied to maintain good burning in the bed and sufficient cooling to prevent clinkering.

Additional air for combustion added above the bed or secondary air is equally important in that it must be added in reasonable quantities at correct velocities and appropriate locations to achieve good gas mixing.

Air control variables are normally not closely monitored in the existing boiler operation, but have significant effects on the efficiency of the overall operation both in terms of the quantities of air used and in the way in which it is used. Improved air monitoring and control could greatly benefit test results.

Another area of interest is the use of duct work opacity meters so that rapid responses to relative changes in particulate loading could be measured during boiler operation in order that the boiler might be fine tuned to minimize the amount of particulate lofted from the fuel bed. This would also make it possible to do relative checks between the level of particulate emitted with different fuels without having to do expensive particulate stack testing for every different fuel or fuel mix.

From the research point of view, the end result of improved instrumentation is a boiler which may be essentially optimized around a given fuel with a minimum amount of trial and error effort and with a minimum amount of stack testing, which is both cumbersome and relatively expensive to accomplish. Detailed stack tests could be used only when boiler operating conditions were optimum for the fuel of interest.

An additional benefit from equipping at least one boiler at Wright-Patterson Air Force Base with sophisticated instrumentation is improved fuel economy on all the boilers. If the operating conditions for one boiler can be more perfectly optimized, then all boilers can be adjusted accordingly and assumed to follow a somewhat similar pattern of controlled setting (i.e., one boiler acts as the pilot facility for the entire base). The economic return for this investment, aside from its research value, is very direct. The base currently burns about 100,000 tons of high quality coal a year. If an overall fuel use improvement of only 1% were achieved by increasing the control instrumentation capabilities of a single boiler, then some $60,000 a year would be saved in fuel. Thus, the instrumentation required could be paid out in one or two years at the most. A fuel savings of 5% or more beyond that which can be achieved with a standard boiler instrumentation would appear to be a reasonable expectation.

SECTION VII

FEASIBILITY OF LOCAL dRDF PRODUCTION

Currently dRDF is supplied to Wright-Patterson Air Force Base by the Maryland Environmental Service's contractor, Teledyne National Corporation. The dRDF is manufactured in Baltimore, Maryland and shipped via truck about 500 miles to Wright-Patterson Air Force Base in Dayton, Ohio. For purposes of a test, this has been a satisfactory relationship, even though the cost of trucking fuel over such a distance invalidates any economic incentives for burning dRDF.

A major cost savings for this source of dRDF could be achieved by shipping the dRDF pellets from Baltimore to Wright-Patterson Air Force Base via rail. Two experimental shipments have been made via rail using covered hopper cars. The results of both attempts have been very similar. The dRDF tends to settle in the rail cars during the period of shipment, a matter of weeks due to scheduling, routing, etc. Even though it arrives in a dry condition, it is very difficult to unload at the fuel receiving facility at Wright-Patterson Air Force Base. A side mounted car shaker would be of great benefit should the long distance shipment of dRDF be considered the most viable for future efforts. The savings in shipping costs between rail and truck would more than offset the cost of additional car shakers. The decision, however, is not so easily reached because of the uncertainty of the future plans of Maryland Environmental Service (MES) for the refuse-derived fuel produced at the Baltimore plant. Telephone conversation with senior personnel at MES indicates that a substantial demand for the refuse-derived fuel has been generated within the State of Maryland. Logic suggests that this purchaser would receive priority over out-of-state purchasers. Hence, MES might simply be unwilling to comply with future contract desires by Wright-Patterson Air Force Base. In addition, the routine long distance shipment of the fuel material is vulnerable to interruption by any number of situations. Thus, with this arrangement, dRDF may be viewed only as an intermittently available fuel as opposed to a secure fuel on which normal operations can be planned.

Based on the circumstances described in the preceding paragraphs, it would appear reasonable to investigate the feasibility and desirability of producing dRDF locally. Two basic management options present themselves for accomplishing local production. The first option is to site a dRDF production plant on Air Force property, which will be owned and operated by the Air Force. The second option is to contract a cooperative situation with a local community or private organization wherein the Air Force acts as a fuel purchaser with cooperative interest in the fuel production process.

The on-base location of a dRDF facility, which would process base-generated waste of approximately [illegible] tons per day and possibly other wastes, offers certain advantages. Principally, the Air Force could exercise complete control over the operation of the production process. Security could be added to the site, as desired, in times of national emergency or civil unrest.

There are also a number of disadvantages to an on-base location. First, there are, as with any developing technology, certain risks which must be assumed by the owner/operator. It does not appear, given manpower demands in other areas, that the Air Force [illegible] assuming the risk of a dynamic technology that requires both technical management and operating crews. Second, a management service must be supplied to the production facility which is capable of providing day-in, day-out operation at the lowest possible cost. Third, once the Air Force commits to such a program, it would be relatively difficult to get cooperative agreements from other federal agencies or local communities in terms of cost sharing or risk sharing. Fourth, the limited waste supply on the base would economically require that wastes must [illegible] to local political whim or with extraordinarily high operating costs for producing a maximum of [illegible] tons of fuel a day based on Wright-Patterson's wastes alone. Such a move would place the base clearly in the position of supplying civil services to local communities in order to gain title to sufficient wastes to offset the operating costs of a dRDF production facility.

An on-base location appears to have a sufficient number of disadvantages to cause the Air Force to seek other possibilities for creating a local dRDF production facility. The single advantage which could be lost is control and security. Since dRDF may be stockpiled (at least several days' supply), reduced security would seem to be of secondary importance compared to the disadvantages of such a facility.

A second option for local dRDF production is the long term agreement to purchase the fuel produced by a dRDF facility owned and operated by a local community. The basic advantages to such an agreement are that the Air Force's exposure is essentially an agreement to purchase fuel at a negotiated price, while any difficulties or risks in financing or operating the facility are absorbed by another group. There are, however, a number of disadvantages to this approach. [illegible] communities generally do not possess the management and technical strengths necessary to develop, own, operate and manage a fuel production facility, even with a single guaranteed customer.

[illegible] the Wright-Patterson area is exercised by Montgomery County. Conversations with a Montgomery County commissioner have indicated that their basic approach to the problem is not to be in the position of technology development or risk absorption. Their first motivation is to dispose of garbage in the most economic and trouble-free manner possible. There is, however, currently a shortage of landfill space in Montgomery County and two incinerators designed to reduce the volume of waste are having severe operational difficulties due to non-compliance with air pollution codes. The general position put forth by Montgomery County officials is, "little interest in creating a resource recovery or technology venture to produce dRDF." They would, however, be extremely interested in participating by delivering wastes to a privately financed, privately owned and operated dRDF production facility. They would pay a reasonable and competitive tipping fee for waste disposal to such a facility.

It is possible that a small community, such as Fairborn, Ohio, might be willing to host such a venture, but the technical resources and management capabilities of a town such as Fairborn are minescule compared with those of Montgomery County. Hence, any expectation of early success or continuous reliable operation would be extremely optimistic.

Given the policy position of Montgomery County, a third option deserves examination. The third option is to negotiate a cooperative purchase agreement with a private venture for the production of dRDF fuel for Air Force boilers. Wright-Patterson Air Force Base's wastes and other local community wastes would be required to meet Wright-Patterson Air Force Base's fuel requirements alone. Thus, the venture would also require an appropriate waste supply agreement with Montgomery County.

The advantages to such an approach are significant. First, the risk in technology development and fuel needs could be shared between the Air Force and other potential fuel customers. Second, a larger facility could be constructed and, therefore, a certain economy of scale affecting overall fuel price would be achieved. Third, a private venture would supply a dedicated management team whose vested interest would make it necessary to maintain the utmost in plant reliability and plant modernization, quality control, etc. Fourth, with a private venture and negotiated agreements, constant fuel quality improvements could be attained as improved definitions of Air Force boiler firing needs were developed. Fifth, a privately financed venture would require relatively short term low risk guarantees from the Air Force, largely an agreement to purchase fuel of a specified quality in a certain quantity at a negotiated price. Sixth, the Air Force risk would be limited to that of a benevolent fuel purchaser. Thus, Air Force expenditures in the fuel production venture would be limited to funds presently being [illegible] purchase fuel. The Air Force would not need [illegible] capability, with a properly negotiated agreement.

There are certain disadvantages associated with a privately owned and managed dRDF production facility. First, the Air Force would be able to exercise less control over the day-to-day operations of the facility, especially during periods of national or international strife, although this concern [illegible] be reduced with take-over clauses or security clauses in the fuel purchase contract. Second, the venture [illegible] difficulties or technology development problems that are not anticipated or within the financial capabilities of the venture (given a reasonable fuel price as the ceiling [illegible] financial risk). At such time, the Air Force would be deprived of the fuel supply. Correspondingly, if additional financing were required and it was determined to be in the Air Force's interest, a buy-out operational contract could be prepared without loss of operation of the facility.

[illegible] the recommended approach is a negotiated agreement with one or more private ventures with the [illegible] is probably adequate to supply Air Force needs. A negotiated agreement could allow for change in fuel formulation to pr[illegible] benefits to the Air Force (e.g., fuel *optimization against boiler performance*). Since the integration of dRDF formulation and combustion is still a developing technology, it is most important that the Air Force maintain a flexible posture which encourages improvements in both production technology and firing [illegible], while [illegible] a competitive cost basis for procurement of the fuel. Such [illegible] basis should be guided by the cost of equivalent BTU's of coal delivered to the air base, adjusted for environmental impacts and costs for both gaseous emissions and solid emissions.

SECTION VIII

dRDF PRODUCTION SCENARIOS

dRDF production can be classified into two scenarios. The first is a generalized comparison for suitability of existing plants or models that could be copies in the Greater Dayton area. The second is identification of those systems that might be considered developmental in nature with unknown levels of technical and economic risk. This classification system is very subjective, given the history of all types of resource recovery facilities.

Seven systems may be considered as reasonably acceptable for dRDF production. Each of these systems has at least an operating pilot plant or is operational.

1. The first plant to be considered is the one operated by Teledyne for the Maryland Environmental Service. This plant presently supplies dRDF to the U.S. Air Force. The basic plant materials flow pattern consists of a receiving area, followed by very large shredders, then a separation process based on air classifiers, next a secondary shredding of the fuel fraction, followed by magnetic separation of the heavy fraction and, finally, pelletization of the beneficiated secondary shredded fuel fraction. Pelletization is accomplished by three pelletizers, all of the ring die and roller configuration, that produce about 1 1/2 tons of dRDF each per hour. The most significant fact concerning this facility is that it has been on line more or less continuously for a number of years. The facility's economics are open to question, since it is subsidized with funds from local, state and federal governments and the contractor operating the facility has no financial stake in the facility or in sales of the product. The facility is very large in capacity, on the order of 1,200 tons of refuse input per day. The overwhelming majority of the facility's output, that is, shredded refuse of fluff fuel quality, is landfilled. A relatively small percentage has been pelletized and delivered to the U.S. Air Force and others for test purposes. Total pellet production is probably under 6,000 tons up to the present time. Additional development would appear to be warranted, because of the relative low yield of the pelletized material vs. the total plant throughput capability.

There are several disadvantages to an attempt to copy this facility. First, it was built originally on a large scale and does not appear to yield well to scaledown procedures. Hence, only a very large capacity plant of this type could be copied. Yet the dRDF yield from the large plant has been almost inconsequential. As a result of the necessity to construct a second large scale plant, very long term contracts or a parent financial organization that is not profit and payback motivated would be required to make the system feasible.

The quality of fuel produced has been marginal in terms of meeting Air Force specification. Ash contents have hovered at the 15% level. Moisture content has been variable and pellet integrity has been variable. Rates of fuel delivery have been lower than those originally required (8,000 tons per year) and fines content has been variable. In addition, the system is inherently inflexible because of its scale of operations.

As a result, any needed developments must be accomplished at a very high cost for incorporation into the system. Therefore, this system is not recommended as a model for the local dRDF production facility.

2. Another system which might be considered has been developed by the National Center for Resource Recovery (presently being terminated) and might generally be described as the pre-trommeling type system. Both the pilot plant in Washington, D.C. (not terminated), and a full scale facility in New Orleans (presently being terminated), have been operated using the general technology. In general, the system consists of trommel screening as a pre-shredding separation step. Following the screening, selected materials are shredded, separated by air classification and magnetic separation or other techniques, secondarily shredded, and conducted to a pelletizer. The pelletizers used are the same manufacture as those used at the Maryland Environmental Service facility. Operating experience with the pilot plant was less than fully satisfactory. While the pilot plant operated well for production of very small experimental batches of material, the general problems of reliably processing material on a day-in, day-out basis were beyond the capabilities of the pilot plant. Fuel deliveries for test quantities of dRDF were generally far behind schedule and very often the fuel material delivered was far below the desired specifications. The full scale plant in New Orleans, while in operation for a reasonable period of time, does not produce a fuel (or at least no market for a fuel has been discovered in the area). The pilot plant pointed out some major difficulties in operating a pelletization plant. Startup time on pelletizers, for example, is relatively extended, e.g., up to three hours. Should, for any reason, the material supply to the pelletizer be lost, the pelletizer must be restarted with resultant low capacity startup period of another three hours. In an eight hour shift, essentially one day's production capacity is lost if anything other than a perfect start is made each day. Interestingly, it was noted that the pelletizer was most readily started each day by combining a supply of fluff with a portion of the previous day's supply of pellets. In

general, the operating experience with a pilot plant of the NCRR type has not been suitably satisfactory to warrant any attempt at duplicating the facility.

3. A third type of plant is being built in Monroe County, New York, by Raytheon Service Corporation. This facility apparently consists of a combination of designs including some materials separation technology originally developed by the Bureau of Mines, air classifiers and shredders. The facility is currently far behind schedule and is still in shakedown, even though contract discussions began in the early 70's. Due to this rather intermittent history, this type of facility does not warrant further consideration until it has a substantial amount of operating history behind it. It should be noted also that this is a very large scale plant and probably far beyond what is required to serve Air Force needs.

4. A fourth type of facility is the Eco-fuel developed by Combustion Equipment Associates. This type of facility utilizes a proprietary technology for embrittling the cellulosic fraction of municipal waste followed by various separation steps until a combustible dust is prepared. Experiments were run on densification of the material. Only by the use of binders could the material be densified and the experience was generally described as unsatisfactory. Further, while the pilot facility operated acceptably after much development effort, the full scale facility is far in arrears and has caused unacceptable financial strains on Combustion Equipment Associates. Given the uncertain future of this technology at the present time, it does not warrant consideration for possible development in the Greater Dayton area.

5. A fifth type of system is totally different from the others. It is basically a wet pulverization and separation system developed by Black Clawson in Franklin, Ohio. A pilot plant is currently available in Franklin and pellets were prepared from this material and tested earlier by the Air Force. Apparently, difficulties with slagging in the furnaces were encountered with these pellets. In addition, Black Clawson, in consortium with others, has constructed or is constructing two major facilities in the 1,500 to 2,000 ton per day class. The first of these facilities, located on Long Island, has ceased operations based on concerns about potential toxic emissions from the stack. While the data presented by the U.S. Environmental Protection Agency would appear to be inconsequential in nature, that agency has not elected as yet to label the data as such and, therefore, the question remains as to the significance of preliminary test results. (Is the presence of toxic materials of specific nature in the stack gases of significance and are these materials present in any form of refuse-derived fuel?) Testing for toxic materials is currently being undertaken at Wright-Patterson

Air Force Base, but the results of these data are not presently available for incorporation [illegible] the uncertain future of this process at the present time, it does not warrant further consideration as a model for construction in Montgomery County to serve the needs of the Air Force.

6. A sixth type of system is based on a unique separating device developed by SPM Group, Inc. It consists of a coarse shred with a low horsepower machine to reduce oversize materials. Following this, separation [illegible] type of conveyor. The fuel quality fraction [illegible] secondary shredded and extruded [illegible] load of this fuel was delivered to Wright-Patterson Air Force Base for very preliminary evaluation as [illegible]. The cubettes were found to burn satisfactorily [illegible], they were in severely degraded [illegible] of at least 50% fines by the time they were delivered to the fuel bunker.

The SPM pilot plant, while not as large in size as the other facilities, does have [illegible] operating history. Included in this history is an evaluation [illegible] of Energy. [illegible] to be forwarded, but has not been received as yet by this contractor.

[illegible] system, a visit was made to the pilot plant, during the time the pilot plant was in operation, to produce 20 to 40 tons of fuel for Air Force use. The location of the pilot plant made it difficult to envision exactly how a system would be constructed [illegible] pilot plant location was far less [illegible] to work and produce a fuel [illegible] fraction [illegible] producing dRDF. Basic advantages [illegible] power requirement, the relative small scale of its operation, and the fact that the separation device seemed to work as well as any other separation device, apparently at lower capital cost and lower operating cost. Of all the systems reviewed to date, the SPM system shows the most promise for direct [illegible] Wright-Patterson Air Force Base. Additional development work is required. However, this would seem to be the case with any other system. Efforts to obtain a copy of the U.S. Department of Energy report [illegible] the SPM pilot plant system will be continued.

A similar [illegible] shredders, and air classifiers is [illegible] careful consideration as a possible precursor to a densified refuse-derived fuel system that may be of utility in Montgomery County and to the U.S. Air Force. The [illegible] modified over a three year period by Midwest Research Institute for the U.S. Environmental Protection Agency and the U.S. Department of Energy. During the period of this investigation, significant improvements were made in the plant, such that the ash content of the refuse-derived fuel produced was reduced from 20% to 10%, while the yield in refuse-derived fuel from the plant was only reduced from 84% to 74% of incoming refuse. Additionally, extensive dust control systems were placed in the plant to extend the life of electric motors. A number of other improvements were made in the plant; however, of greatest interest for purposes of this report is the fact that the net cost for producing the fuel was estimated to range from approximately $14 per ton in 1976 to approximately $11 per ton in 1978. Gross cost for fuel production was approximately $26 per ton of refuse processed in 1978. For Air Force purposes, if a similar plant were built, the gross cost of $26 per ton could be reduced to $20 per ton (if a $12 per ton tipping fee were applied). (Assumes 50% dRDF yield and no other revenues.) The cost of densification must be added to this base cost. Densification may range from $3 to $15 per ton depending on whose data and opinions one wishes to subscribe. Thus, a net cost for producing dRDF of $23 to $35 per ton F.O.B. the plant is conceivable. A selling price would additionally include land value, cost of fuel delivery, liability insurance, taxes, management and marketing fees, and profit adjusted for perceived risk. Given the increases in the cost of money, equipment and construction, a delivered price ranging from $40 to $60 per ton may be expected.

The Ames plant produced approximately 35,000 tons of RDF fuel per shift year, which places it in the correct size range for Air Force fuel purchase requirements. Should the Air Force desire to own and operate a facility or to subsidize in an extensive manner the financing of such a facility, the Ames model is probably the most developed and most reliable, currently available one in the United States in the appropriate size range. Additional study and consideration of the Ames process design and operating experience as a model for a local dRDF plant is recommended.

A number of totally undeveloped design concepts deserve consideration for their potential impact on dRDF production in the Montgomery County area. These concepts fall primarily in the basic research regime and are largely unexplored. Therefore, they have been included in the Appendix, Research Briefs, for possible consideration or investigation in the future. In view of the drastic cutbacks in federal funds to sponsor a research in the refuse-derived fuel area, the probability of these research projects being realized is extremely slim. Therefore, they cannot be looked to as a possible contribution to the need for more reliable and improved quality densified refuse-derived fuel production processes.

[illegible]

[illegible]

[illegible] on Air Force Base may be [illegible] those of immediate concern and those [illegible], one year away). In the immediate future, [illegible] and October 1982, two [illegible] load, [illegible] ational [illegible]

A [illegible] incorporated [illegible] to the present time, [illegible] be carried [illegible] possible. This [illegible] describing both use criteria [illegible] to [illegible] high load test burn [illegible]

[illegible] preliminary investigation [illegible]. Unique odors and skin sensations suggest that some sort of skin sensitization is created by dRDF firing. The effect [illegible] associated with dust generation by [illegible] in the pellets. [illegible] consequence, [illegible] possible other than to [illegible] preliminary [illegible] own sensitizers or other types [illegible] are present in the dust and in the atmosphere [illegible]

[illegible] in the near [illegible] together in this report and the conclusions offered. Three general research needs are defined.

First and of highest priority is an improved quality of fuel pellet. This need is based on the [illegible] criteria described heretofore and [illegible] configured, [illegible] would alleviate many of the potential [illegible] operational problems one might [illegible] to accept, store and fire dRDF.

Second, to accurately evaluate various fuels for their impact on boiler efficiency, the boiler operation must be absolutely optimized against each fuel's performance characteristics. Improved boiler monitoring instrumentation is a mandatory requirement in a precise evaluation. Additional benefits to the Air Force would be at least marginally improved operation of all boilers, based on the control techniques established with the test boiler.

The third need is for a local synthetic solid fuel production facility whose fuel formulation capabilities can be integrated into a boiler performance test program. The local fuel production facility, given the circumstances in Montgomery County and the needs of the Air Force, would be owned and operated by a private group. Wastes must be supplied by local government, i.e., Montgomery County and Wright-Patterson Air Force Base. A conditional contract to supply fuel to the Air Force must be developed with the management of the fuel production plant to facilitate private financing for the venture.

Due to the need for additional fuel formulation development based on the use criteria and an integral boiler performance test, a negotiated agreement is probably most beneficial to the Air Force. A competitive cost contract implies that a true and exact specification of a need can be written. In this case, the need is general and, thus, a written comprehensive description is not possible at the present time. Any attempt to specify needs would undoubtedly produce an inferior quality fuel based on a financially marginally viable venture, with no capability for responding to changing Air Force needs as these are further defined.

The incorporation of coal into the pellet production process promises to achieve most, if not all, of the fuel characteristic goals implied by the use criteria described heretofore. Thus, the fuel processing capability that is required is one that should evolve from pure dRDF production into an integrated dRDF/coal pellet. This would, in turn, reduce new boiler design requirements to those comparable to a coal-fired facility.

In addition, an integrated fuel production and boiler test program would provide new insights into the impact of manufactured fuel based on a number of materials as compared with coal only systems. For example, fuel cost could be decreased by the incorporation of less valued materials into the fuel mix. Typical materials might include sewage sludge, municipal wastes, high sulfur coal, peat, biomass, etc. The end product should be a superior fuel that would perform better than run-of-the-mine or processed coal. The use of these materials would contribute greatly to the solution of problems external to immediate base concerns. Realization of the potential of such a system, however, requires an integrated fuel formulation and production facility and boiler performance test capability.

Such a program promises a unique fuel/boiler optimization technique that may be expanded to benefit all boilers at Wright-Patterson Air Force Base as well as other solid fuel boilers at Air Force bases in the United States. [illegible]

1. Improved synthetic solid fuel bearing strength so that conventional handling equipment may be used.

2. [illegible] so that boilers may be [illegible]

3. Improved [illegible]

4. [illegible]

5. [illegible] resources.

6. Improved boiler efficiency because of uniform fuel quality.

7. Reduced [illegible] emissions from boiler because of reduced [illegible]

8. [illegible] be managed on a predictable basis

9. [illegible] controls added to fuel.

[illegible] in steam production costs compared with low [illegible] with scrubbers.

The unique mixture of materials and interests that would be represented in such a project should create extensive cost sharing opportunities with other federal agencies, private corporations, and local [illegible] Air Force provides the test facility [illegible] with improvements to facilitate monitoring of the effects of the fuel on boiler operations and purchases the fuel at a reasonable price, [illegible] third of the value of the project would have been made. Yet the real cost to the Air Force would be essentially zero because the fuel purchased should be cheaper than fuel presently [illegible] one-third of the funds required [illegible] own and operate the fuel production facility and ultimately commercialize its operation, only one-third of the resources needed for the entire project would be required [illegible] primary responsibility and interest in this area include the Department of Energy (for both the incorporation of high sulfur coal as a fuel material and the use of refuse as a fuel material) and the Environmental Protection Agency (for the incorporation of sewage sludge as a fuel material, as well as the suppression of sulfur emissions by fuel preparation techniques).

The integrated fuel production and boiler test program should be given highest support and funding priority because of the very high value of the program results and the many cost sharing opportunities.

The end product of the test program would be an optimized fuel and boiler combination for Wright-Patterson Air Force Base with a local fuel production facility capable of supplying all the fuel needs of Wright-Patterson Air Force Base at an overall cost savings when compared with present operations. The desired results should be attained about two years after program initiation for an overall cost of $4 million to $5 million. This development program cost compares quite favorably to present Wright-Patterson annual expenditures of about $5 and 1/2 million for low sulfur coal.

SECTION X

CONCLUSIONS AND RECOMMENDATIONS

The [illegible] dRDF have been examined from a variety of perspectives. Only rarely in large, complex development programs do results tend to support a single broad conclusion leading to a relatively specific recommendation. This is the case with all efforts to maximize the [illegible] of dRDF.

The [illegible] and recommendations are:

1. An integrated [illegible] facility and boiler performance test program [illegible] at Wright-Patterson Air Force Base on a pilot [illegible]

2. The dRDF fuel [illegible] incorporating local fuel resources in addition to refuse. The fuel production facility should incorporate both the [illegible] and the willingness to produce varied solid synthetic fuel for [illegible] performance test results indicate.

3. The [illegible] should be equipped with the necessary monitoring and control devices to minimize the time and cost of optimizing boiler performance against a specific fuel and to develop fuel formulation modification requirements for succeeding tests. [illegible] improvements in boiler [illegible]

During the time necessary [illegible] the recommendations offered by this report, several [illegible] aspects should be investigated concerning the utility of the present dRDF formulation. These are:

1. A preliminary investigation of the occupational health and safety [illegible] dRDF.

2. A high load boiler performance test on dRDF alone and in blends should be carried out.

3. Routine firing of dRDF should be continued at Wright-Patterson Air Force Base [illegible] months to facilitate high load testing and to [illegible] investigations already initiated.

4. Continuation of a program [illegible] a multi-fuel boiler design

specification for Air Force procurement purposes.

APPENDIX A

RESEARCH BRIEFS

APPENDIX A

INTRODUCTION

The following briefs are to supplement the principal conclusions and recommendations and highlight specific technical questions which may have significant economic impact on the utility of densified refuse-derived fuels. The briefs are intended only to introduce the salient points and desired outputs from specific investigations. They are not prepared in sufficient detail to act as program management guides, but rather to be used as the basis for the preparation of such guides.

The briefs have been included to overview a best-effort description of a high payoff dRDF development program. They do not describe all the tasks that could be required, nor are they prioritized.

R&D COST SHARING POSSIBILITIES

When this contract effort was initiated, one of the major goals was to develop R&D program tasks to include extensive cost sharing with other groups by the U.S. Air Force. At the start of the program, the major budgetary changes that would be sweeping through the federal government were not recognized. Several possible sources of cost sharing were available at that time. The first of these, and the most important, was the U.S. Department of Energy in its Office of Energy from Urban Waste. At the start of this particular management effort, the Department of Energy program budget was approximately $12 1/2 million for R&D and $100 million in loan guarantees for commercialization of technologies utilizing urban waste. The situation has changed dramatically. In fiscal 1982, this program will have no funds for commercialization purposes and $3 million for R&D. Current plans call for the 1983 budget to be zero dollars. Hence, new program starts for this group are unlikely.

A second agency which had formerly been extensively involved in dRDF and had invested several millions of dollars in R&D evaluation is the U.S. Environmental Protection Agency, Municipal and Environmental Research Laboratory. This group is now no longer active in this program area and has terminated all program functions. Hence, cost sharing with this group is not a possibility.

Other federal agencies that might have cost shared work were the U.S. Bureau of Mines and the U.S. Department of Commerce. The U.S. Bureau of Mines is dropping all work on urban waste and historically only evaluated urban waste as a source of minerals. The U.S. Department of Commerce has never had an extensive R&D program and has devoted its very small budget to development of standard methodologies for evaluating the properties of urban waste. The future for this program is uncertain at the present time.

Other programs within the Department of Defense, directed by the U.S. Navy or the U.S. Army, could be cost sharing candidates; however, one would assume that these sources are already closely allied to the U.S. Air Force program and that any possibilities for co-funding projects have been explored.

The last major governmental group that might be willing to participate in jointly funded programs are the various state energy agencies. These would, of course, be specific for Air Force bases located within that state's borders. Hence, a case by case programatic decision as to the location of development programs would have to be made in order to qualify for possible co-funding. Given the general revenue climate, the prospects of co-funding through this group look very slim, with the single exception of the Maryland Environmental Service which, to date, has not co-funded programs with the Department of Defense.

Thus, the historic sources of co-sponsorship of alternative energy programs seem unavailable for future programs. Interestingly, the economic pressures and the needs to develop these fuels both from a secure operations point of view as well as economy of operations, have never been greater. Natural gas prices in the Cincinnati area, for example, increased 23% with an additional 10% expected before the end of the fiscal year. In addition, these delivered supplies of fuel which cannot be stored readily on base continue to be extremely susceptible to interruption through the vagaries of the marketplace or domestic unrest. In conclusion, while the needs for alternative approaches to fuel resources have never been greater, the possibility of additional financial resources beyond those generated by the Air Force look most unpromising; efforts are probably better expended at carefully planning and tailoring programs and increasing management expertise in these areas, as opposed to seeking cost sharing funds.

A final area that might provide effective cost sharing is with major industries. Cost sharing would only be possible where industry had waste it wished to dispose of in a suitable manner or wherein they thought participation in a specific program would create new business opportunities. In both these situations, at least a one year delay in any project that was attempted would be required in order to create a negotiating environment that would provide for an equitable agreement on the part of all parties. Given the current business environment, i.e., a downturn (best projections are another 12 to 18 months of slump) along with very high interest rates, the possibilities for financial participation in many R&D projects do not look promising. The one approach which could be co-financed would be the creation of a new synthetic fuel industry as described in the body of the report. In this, a consortium might be organized that would assume the bulk of the program risk, provided long term payoff mechanisms (based on demonstrated success) were included in the agreement. The Air Force would be required to make double use of certain types of operational funds by using them as an incentive to spur development. Such an approach would require more administrative capability, but would reduce Air Force development costs and ultimately reduce boiler operating costs at minimal risk to the Air Force.

CO-GRINDING BENEFICIATED REFUSE AND COAL

Background

Considerable effort and energy in the processing of refuse is consumed by the size reduction unit process. Several approaches have been pursued in the past, one of the earliest being the use of very large hammermills for shredding the entire refuse stream. The suitability of this technique has been questioned because of its undesirable property of forcing non-[illegible] the combustible fraction in such a way that they could not be separated, thus creating a high ash content fuel material. [illegible] preceding shredding has reduced the non-combustible content of the fuel fraction while reducing the horsepower requirement [illegible] shredder. Light duty shredders have been used as a pre-separation [illegible]. Even so, shredders have not been perfected which deal uniformly with all types of materials in urban waste flows. For example, synthetic fabrics are particularly troublesome to high speed shredders of either the heavy or light duty design. As fabric passes through relatively undamaged by the shredding operation, it is sized so as to obstruct additional unit processes because of its high tensile strength and [illegible] flexibility.

A different approach which has not heretofore been explored is the use of low energy grinding devices, such as rod mills and ball mills, along with a grinding agent. The use of grinding agents to facilitate the grinding of difficult to grind materials is old technology. It has been successfully applied, for example, in the use of large shredders for consuming automobile bodies. The chunks of steel act as a grinding agent for the high tensile strength fabric portions of the automobile body, resulting in uniform shredding with minimal wear on the shredder. Based on the recommendations presented heretofore, it is apparent that pre-mixing of coal and refuse is a desirable step. There is a need to examine the merits of combined size reduction of beneficiated waste and coal in order to enhance densification unit operations on the combined materials. Rod mills would seem to be an ideal choice, as they are capable of reducing coal rather directly to finely divided particles. They should be equally effective in the presence of chunks of coal in mascerating and reducing the size of refuse. They may further be designed so that they retain, for longer periods of time, those portions of the beneficiated refuse stream that are more difficult to reduce in size.

Approach

The purpose of this project is to perform comparative exploratory research on the efficacy of co-grinding beneficiated refuse and coal in various types of shredders. This should be carried out using both run-of-mine and pre-sized coal samples, as well as beneficiated refuse as might be obtained from a trommel. Preliminary estimates of capacity and particle size distribution of refuse and coal fractions are required, as well as the gross effect of varying the coal/refuse ratio. In addition, the finely divided product mixture should be evaluated for its compatibility with densification processes. In theory, the denser, more finely divided and uniform mixture should pelletize considerably easier than shredded refuse alone and produce a superior pellet. Based on the results of a preliminary program, a decision could be made as to whether or not to develop a pilot plant facility for additional evaluation.

Program Cost and Desired Results

The estimated cost of such a research program is approximately $150,000 over 12 months duration. It should yield a spectrum of data for limited size samples indicating the comparative efficacy of rod mills, ball mills, and possibly hammermills for grinding mixtures of beneficiated refuse and coal, as well as the impact on the productivity of conventional pellet mills.

BALED REFUSE AS A MODIFIED SPREADER STOKER BOILER FEED

Background

One approach to the use of densified refuse as an alternative boiler feed is to modify the boiler to accept baled refuse as a feedstock. In general, a feeder mechanism would be replaced with a feed chute capable of accepting bales. At the lower end of the chute, a chipper would remove chunks of the bale and broadcast them to the boiler, much as a conventional spreader [illegible]. If modification of the boiler feed system is not desired, then the bale feeder and chipper unit operation could be located [illegible] existing solid fuel handling, storage and feed system.

The principal advantage achieved by incorporating bales into a densified refuse-derived fuel production and use system is the ease of transporting and storing baled refuse, as well as the ease of handling the fuel. Problems such as [illegible], and fuel quality degradation using bales would be minimized. In addition, bales may be stored out-of-doors in minimum space with minimal degradation beyond the surface layer of the bale.

Approach

A feasibility study of using bales as a boiler feed material should be prepared. Initially, a paper study is envisioned in order to examine the advantages and disadvantages of this densified refuse-derived fuel system, as compared with conventional approaches.

Program Cost and Desired Results

The estimated cost for the program is $45,000 and the duration would be about six months. Output from the project is a preliminary feasibility study indicating whether the use of bales as a boiler feedstock offers sufficient economic advantages to warrant experimental investigation.

PRELIMINARY TESTING OF THE IMPACT OF BOUND OXYGEN AND MOISTURE IN FUEL ON FUEL BED TEMPERATURE AND UNDER-FIRE AIR REQUIREMENTS IN SPREADER STOKER BOILERS

Background

As indicated in the literature brief, on a theoretical basis a selected percentage of moisture bound in the fuel, along with the fixed carbon and any oxygen that may be in the fuel, may be utilized to contribute to a general reduction in the rate at which underfire air must be used to control fuel bed temperature and prevent clinkering. Under reducing conditions in the fuel bed, moisture present in the fuel contributes to a water gas shift reaction so that the fixed carbon is evolved from the fuel bed primarily as carbon monoxide yielding approximately 80% of its heating energy while burning in the gaseous phase above the fuel bed. A reduction in underfire air reduces the amount of particulate lofted from the bed and, thus, the load on the dust control system. A potential for slagging and deposition should be reduced throughout the boiler. The operation of the fuel bed at lower temperatures suggests increased capability for accepting fuels whose ash fusion temperatures are lower than those of premium coals.

Approach

A stockpile of fuel of known bound moisture content will be prepared to optimize the theoretical minimum amount of underfire air that could be required. A boiler will be operated on this fuel, underfire air will be reduced to the required level, and overfire air will be correspondingly adjusted down until opacity increases. Boiler efficiency will be measured and clinkering characteristics, if any, will be observed. Underfire air will be marginally increased if clinkering is observed. Operating parameters and efficiency will be monitored and, thus, cost of the boiler operation determined.

Program Cost and Desired Results

The cost for preliminary testing, assuming a fuel production facility can be located with the capability of producing the fuel of the desired characteristics, should be approximately $150,000 to $175,000 for a one to two week test. This assumes that sufficient fuel is prepared for operating the boiler approximately two and one-half days, or about 50 tons of fuel for a small boiler. A longer term test would be contingent on a supply of the desired fuel at the desired specification. The preceding cost also assumes that the boiler is capable of being operated in the manner desired and that only portable additional instrumentation is required to closely monitor air flow rates in the various air supply systems.

Results required from the experiment are a demonstration of ability to reduce bed temperatures by reducing underfire air flow, and at the same time, not create clinkering which would cause serious problems in the boiler operation. The desired output is to demonstrate that the overall boiler efficiency can be raised several percentage points because of the reduced requirement for excess air in the boiler. Should the initial experiments be successful, a long term experiment to determine the impact of corrosion, deposition and routine maintenance costs should be carried out. All of these operating expense factors should be [illegible].

OCCUPATIONAL HEALTH AND SAFETY IMPLICATIONS OF FIRING dRDF ON A LONG TERM BASIS

Background

One of the areas that has received little attention in all of the dRDF testing to date is the potential health implications for firing dRDF. As pointed out in this and other reports, dusting at transfer points and in the handling of dRDF is a severe problem with the present dRDF formulation. The health implications of this dust are unevaluated at the present time. The dust is anticipated to contain a certain quantity of heavy metals and certain organic compounds that may be of health significance. In addition, data produced in unpublished form by operators of municipal incinerators in the 60's indicated that the dust was of some health significance and that protection for those continuously exposed to the dust was a necessity. In addition to this, dust from shredded refuse has been demonstrated to be more combustible than coal dust, although somewhat less combustible than flour and other finely divided organics. Several explosions in shredders operating on municipal refuse have been reported in the technical literature. As a result of these facts, an occupational safety and health preliminary scan is required in order to begin evaluation of the dust presence in the Wright-Patterson facilities to determine if significant impacts are created by dRDF firing.

Approach

A preliminary scan of the area using high vol samplers and appropriate analytical procedures is required. The preliminary scan would collect samples close to fuel handling and operator locations over a period of time. The samples would be analyzed for heavy metal concentration, known skin sensitizers and known organic carcinogens. The test results should be interpreted by experts in the occupational health field to determine if additional field investigations are required and if additional dust controls are required for health reasons.

Program Cost and Anticipated Results

This preliminary investigation should require six months and $75,000 to accomplish. The results should provide a definition of the severity of the occupational health needs associated with the use of dRDF as presently formulated.

HIGH LOAD RATE BOILER PERFORMANCE TESTS ON dRDF BLENDS AND dRDF ALONE

Background

Considerable testing of dRDF in various operational modes has taken place in the past. The Environmental Protection Agency has sponsored tests at small heating plant boilers under low load conditions and at an industrial boiler under varying load conditions. However, this work has not definitively demonstrated boiler performance under sustained, uniform high load conditions. Mechanical difficulties, lack of load on the boiler, or variable boiler loads have reduced the value of data collected. As a result, there is a need both for Air Force and industrial purposes to have a high load dRDF demonstration with various blends and under sustained uniform load so that small differences in performance can be defined.

Approach

The basic approach would be to select a boiler at Wright-Patterson Air Force Base (probably in building 770) that normally operates under very high uniform load conditions, support this boiler with appropriate fuel metering equipment so that accurate measurements of fuel consumed can be used, and carry out boiler performance tests across several dRDF/coal blends and, hopefully, on dRDF alone, in order to define the end points beyond which a normal coal designed boiler can perform on dRDF. A contractor, such as Systems Technology, KVB of Minneapolis, Minnesota, and numerous others are qualified to carry out this type of evaluation. The program should consist of the development of a test protocol and boiler firing protocol, which is clearly explained to boiler operators, so that fuel is marshalled and utilized in the most effective manner. An important criteria in the protocol is an adequate period for boiler operators to familiarize themselves with the idiosyncrasies of firing dRDF/coal blends, so that boiler performance is approximately maximized by the usual trial and error approach. The protocol must then be followed rigorously by the contractor in order that measurements may be made on handling properties of the fuel under high load conditions, boiler efficiency and environmental performance.

Program Cost and Desired Results

Such a program will probably cost $300,000 to $350,000 exclusive of fuel costs. Anticipated duration is nine months. A technical definition of the end points for boiler performance, when using various dRDF blends and dRDF alone, is desired. Questions to be answered are: how much of design load can be supported on a given blend without equipment modification; what are the environmental impacts and performance impacts of the sustained operation in this regime?

APPLICATION OF BINDERS TO DENSIFIED REFUSE-DERIVED FUEL PELLETS

Background

Considerable effort has gone into the preparation of densified refuse-derived fuel pellets on a production basis. Less effort has been directed toward how these pellets might be constructed in a more suitable manner to give them improved properties while decreasing or at least maintaining the [illegible]. One specific area that requires dramatic improvement is the stability and weather resistance of the pellet. [illegible] are available on the market and few, if any, of these have been examined for their compatibility with densified refuse-derived fuels. The only reported work in this area presently is [illegible] by the [illegible] Center for Resource Recovery to use waste motor oils as a binder and waterproofing material. The results of this study were negative. Many other binders, such as gelatinized cornstarch and latex emulsions, may provide a superior pellet and increase its weatherproof qualities to a considerable degree. One of the literature briefs included herein suggests that extensive study has been carried out to select binders for coal and this data should be readily translatable to refuse-derived fuel. Hence, exploratory research on a production level with binders would seem worthwhile.

Approach

In general, binders should be examined through solicitation to manufacturers for compatibility with their particular production processes and the product requirements. Perhaps half a dozen binders or combinations of binders should be procured and delivered to Maryland Environmental Service and other dRDF suppliers (i.e., Ames, Iowa) for incorporation in 20 to 50 ton batches of pellets, so that these pellets can be examined on an empirical basis for handling and combustion characteristics.

Program Cost and Desired Results

This study should not require more than six to nine months. Anticipated cost is \$50,000 to \$100,000 including all materials and modification of equipment to include binders, laboratory evaluations of the pellets, etc.

The result of the project would designate a binder that would yield a superior dRDF pellet that would minimize dusting problems, allow for at least some outdoor storage, increase the handling characteristics of the pellets and increase pellet bearing strength.

MULTI-FUEL BOILER SPECIFICATION: CRITERIA DEVELOPMENT AND OVERSIGHT COORDINATION

Background

The desired end product from the dRDF test program, along with several other programs currently being conducted by the Air Force, is the development of a multi-fuel boiler specification for procurement purposes for renewal of facility boiler capabilities in the future. Considerable data must be developed around boiler capabilities as operated against the various fuels in order that a specification will be developed which will encompass either all of these capabilities or as many as technically feasible. The boiler should operate efficiently and be cost effective on any of the selected fuels, while meeting local and national environmental performance laws.

Approach

A draft boiler specification document should be prepared based on existing boiler specifications by those familiar both with alternative fuel burning and normal coal firing. The document should be circulated to boiler manufacturers for review and comment, possibly on a limited subcontract basis in order to assure reasonable participation. On receipt of review comments, these comments should be reviewed and possibly incorporated; the redrafted document should be circulated again and reviewed by Air Force procurement specialists and alternative fuel specialists. A final specification document should be prepared based on all of the comments generated.

Program Cost and Desired Results

Time required is estimated at 18 to 24 months. Anticipated cost is $150,000 to $300,000. A written specification suitable for procurement purposes by the Air Force for obtaining a multi-fuel test boiler is the desired product.

INVESTIGATION OF CORROSION, SLAGGING AND FOULING THAT MAY BE INITIATED OR EXACERBATED BY COFIRING OF dRDF

Background

One of the major concerns of all boiler operators is the impact of fuel characteristics on the reliability, life and maintenance costs of boiler construction materials. Generally, boilers have been designed based on coal specifications which have minimal chlorides and, to a certain extent, other acid forming [illegible]. These materials are present in dRDF and the impact on boiler tube life is unknown. Preliminary investigations on a very short [illegible] has raised a problem. However, data produced by short term evaluations of corrosion are often misleading and erroneous because effects may be cumulative, may be accelerated by the temporary presence of [illegible] compounds, etc. Thus, long term monitoring for corrosion, slagging and fouling characteristics of boiler tubes and grates, superheater tubes, sidewalls, etc. is a requirement in order to fully evaluate the potential impacts of dRDF on boiler operations, future boiler design criteria and procurement specifications.

Approach

Work initiated with the National Bureau of Standards should be continued and accelerated in order to implant corrosion tabs at strategic locations in boilers at Wright-Patterson Air Force Base for a minimum period of 12 to 18 months. These tabs should be designed in such a way that portions may be removed periodically for evaluation in order to develop a continuous spectrum of the impacts of dRDF firing. Obviously, dRDF must be fired extensively or for the majority of the period of time during which corrosion tests are being made in order to determine the impacts of the fuel on the metal surfaces. Based on this, and with knowledge of the corrosion of various metals, recommendations may be made for specified levels of various compounds in dRDF or dRDF presently available may be evaluated against corrosion control requirements in the fuel specification.

Program Cost and Desired Results

The program cost should be approximately $75,000 to $100,000 over 18 months.

A definition of the corrosion potential of dRDF as presently configured on a preliminary, [illegible] extended term basis should be made. Potential corrosion problems should be defined along with a requirement for specified levels of compounds in dRDF that would tend to minimize the impacts as they are measured.

DENSIFICATION OF RDF PREPARED IN AMES, IOWA

Background

One of the few refuse-derived fuel plants in operation over a period of time in the United States is located in Ames, Iowa. This plant underwent extensive modifications and evaluation sponsored by the U.S. Department of Energy and Environmental Protection Agency, as described in the Literature Briefs. It presently produces a high quality, fluff type fuel which could be supplied to densification modules. Because it is substantially lower in ash content than other RDF's described (i.e., 10% ash), it should produce a higher quality densified refuse-derived fuel. Hence, an evaluation of the practical aspects of densifying this material would be very beneficial.

Approach

The project could, on a least cost basis, be carried out without the creation of a fixed pilot plant. Several tractor trailer loads of the fluff fuel may be procured and delivered directly to pilot plants maintained by pellet mill manufacturers for pelletization. The test should be observed by those experienced in pellet production with beneficiated refuse in order to determine the relative rate at which the pelletizer processes this prepared material. In addition, exploratory experiments could be undertaken to enhance the material in order to increase its rate of pelletization. The pelletized fuel (perhaps 20 to 100 tons total) could then be delivered to Wright-Patterson Air Force Base for short term burn tests including a preliminary evaluation of its handling and storage characteristics.

Program Cost and Desired Results

The overall program cost is approximately $150, 000 and the duration is six to twelve months. The results desired are a preliminary assessment of the compatibility of the fluff produced at Ames with densification subsystems and the quality of the fuel which is prepared. Hence, quality related laboratory analyses of the fuel must be carried out.

PRELIMINARY INVESTIGATION OF THE COMPATIBILITY OF dRDF WITH FIXED BED AND CLOSE-COUPLED GASIFIERS

Background

Many oil and gas fired boilers are in operation in both industry and the Armed Forces. The cost for oil has gone up dramatically in the last decade and the cost for gas is starting on the same rapid and extreme climb. Delivered gas prices in the Cincinnati area are in excess of $4 a million BTU's and expected to go to $10 a million BTU's within two to three years. Solid fuels, such as low sulfur coal and other synthetic fuels, promise to be significantly lower in cost than gas and oil. However, the cost of replacing a boiler greatly reduces the desirability of attempting to use solid fuels. Gasifiers promise to directly convert solid fuels into adequate substitutes for gas or oil with which to fire boilers. Little investigative work has been carried out to determine the compatibility of gasifiers with densified refuse-derived fuel pellets. Some preliminary work done by university researchers indicates the approach to be extremely viable on a laboratory scale.

Approach

A supply of densified refuse-derived fuel must be obtained. Several versions of gasifiers, including those that are typical of the close-coupled, moving grate type, the starved air type, and the fixed bed multi-vessel type, should be constructed in a pilot scale. These gasifiers should then be operated with the pellets to determine their reliability of operation, the quality of gas supply, and heat release rates which they are capable of delivering. Their performance under varying load conditions must be evaluated. Ash loadings on the boiler should be measured to ascertain compatibility with the ash handling characteristics of typical gas or oil fired equipment.

Program Cost and Desired Results

The program is estimated to require $250,000 to $300,000 and 12 to 18 months to carry out, since pilot scale equipment will be constructed or purchased and operated for evaluative purposes. The final report concerning this work should include a description of the operating characteristics of the gasifier, relative cost of operation and its effectiveness in following boiler load, and its compatibility with existing gas and oil fired equipment. The next step in the overall acceptance of gasifiers would be to construct a pilot scale unit at an existing boiler for detailed field evaluation, assuming adequate supplies of dRDF were available.

APPENDIX B

BRIEFS FROM THE PERTINENT LITERATURE

APPENDIX B

INTRODUCTION

The following briefs have been provided to describe the salient points of knowledge created by the work of others. This knowledge can be used to give direction to the efforts of the U.S. Air Force to increase the utility of dRDF both for specific military requirements and for application to other industrial boiler operations. Included with each brief is a section entitled Critical Comments, which is intended to emphasize perceived weakness in the work being reviewed and to highlight those findings of greatest significance to future U.S. Air Force sponsored dRDF programs.

The briefs provided are not intended to be either an all encompassing literature search or an exhaustive summation of the information available in each citation. The briefs provided do include the most recent reports describing dRDF experimental programs conducted by others. They also include data, information and concepts from other unrelated or parallel investigations, which may be interpreted to have produced information of great importance to future Air Force dRDF programs.

The briefs are arranged in a reverse chronological order, although all of the work was completed in the 1970's and most between 1977 and April 1981. Information from these briefs has been used as a basis for some of the Research Briefs in Appendix A, which in turn support the principal recommendations of this report.

HIGH PRESSURE COMPACTION AND BALING OF SOLID WASTE

Performing Organization: American Public Works Association

Sponsor: U.S. Environmental Protection Agency, Office of Solid Waste Management Programs

Grant No. D01-UI-00170

Summary

The objective of this research effort was to obtain production scale information on the various parameters that affect the compaction of refuse into bales which are readily handleable for long distance shipping. Included in the effort was the use of an experimental press to develop performance specifications for production scale compaction equipment and to define the durability and utility of the bales during and after shipment via both test mechanisms and actual transshipment by rail car over 700 miles. Data was produced on the effect of various refuse components on the density of the baler, the gross results of baling operations, the types of materials which could and could not be baled satisfactorily, and the necessity of exterior strapping.

Conclusions

Mixed municipal solid waste was found to bale satisfactorily in a range of from 1,500 through 3,500 psi. Increased pressures up to 6,000 psi were tested; however, no additional benefits were noted. Separate components of mixed waste, such as rubber tires, were found not to bale under any circumstances. Increased moisture content of the bales tended to reduce their coherence and cause rapid deterioration. Suitable moisture contents of from 10% to 30% were indicated by the results. Baled densities, depending on the compaction pressure applied, ranged from 82 to 92 pounds per cubic foot during the compaction effort. After springback of the bale (that is, release from the baler), densities ranged from 52 to 65 pounds per cubic foot depending on the baling pressure utilized. Cost for the baling operation based on 2.9 million cycle life for the baler was estimated at approximately 50¢ per ton in 1969. Experiments were run with adhesives or binders; however, these were not found to be beneficial for the purposes of the research. Baler capacities averaged about 200 pounds per minute. Springback of the bales amounted to as much as 95% of the original compacted volume during a 24 hour period. The major factors found to affect the stability of the bales were compaction pressure, time of pressure application and the moisture content of the waste. Exposure of the selected bales to three weeks of outside weather during February to May (in Chicago) did not cause appreciable structural deterioration. Spillage amounted to less than 1% of the bale during rail haul experiments.

Critical Comments

The compaction pressures reached in the baler are equal to and sometimes exceed those found in pellet mills. The baler offers uniform compaction across the face of the material, whereas pressure differentials in the pelletizer probably exist. Baling offers another technique for producing large quantities of densified refuse, perhaps at lower cost than does the use of pellet mills or other types of densification. Volume reductions in the baler were as much as 15 to 1 with springback reducing this by approximately half. Final densities were acceptable for maximum weight shipment of material by truck or rail with minimum volumes.

SYSTEMS ANALYSIS FOR THE DEVELOPMENT OF SMALL RESOURCE RECOVERY SYSTEMS

Performing Organization: Systems Technology Corporation

Sponsor: U.S. Department of Energy, Assistant Secretary for Conservation and Solar Energy, Office of Buildings and Community Systems

Contract No. AC01-77CS20026

Summary

This program summarized data concerning various small scale resource recovery systems ranging in capacity between 50 and 250 tons per eight hour day. They were compared for cost and efficiency on a standardized basis in order to identify components which required additional R&D and which had the greatest impact on the systems' performance.

Conclusions

None.

Critical Comments

No conclusions were offered in the document that were of value to this research program. Useful data, however, for the potential fabrication of a resource recovery facility was developed and can be selected based on a number of systems displayed. The document is extremely useful for producing comparative cost data, although there is no validation of the cost data or explanation of how this was generated. The report does not identify research needs beyond the scope of existing systems; i.e., no recommendation was made for future studies.

EVALUATION OF EMISSIONS AND CONTROL TECHNOLOGY FOR INDUSTRIAL STOKER BOILERS

Performing Organization: Battelle Columbus Laboratories, Columbus, Ohio

Sponsor: U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina 27711

Contract No. 68022627

Summary

The report is prepared essentially in three separate, related sections; hence, the review and critical comments will be organized in a similar manner.

Phase I - Alternative Fuels Evaluation

Phase II - Control Technology Evaluation

Phase III - Limestone/Coal Pellet Development

Phase I - Alternative Fuels Evaluation

Summary. A 200 kw (very small) stoker boiler was used to evaluate characteristics of emissions from combustion of a variety of coals, including coals that could not be conveniently or economically evaluated in a larger industrial system. The stoker was operated in two modes, an underfeed mode and a spreader stoker mode.

Emissions Results. For underfeed stoker, under 10% of the fuel nitrogen was converted to NO. For spreader stoker, between 10% and 20% was converted to NO. Coals naturally high in calcium and sodium and those treated with these elements retained significant percentages of sulfur in the ash. Retention of sulfur in the ash was as high as 20% for coals with small amounts of calcium and sodium but significant amounts of iron and sulfur. Bed temperatures in the laboratory stoker were lower than those in an industrial stoker. Particulate loadings did not correlate with ash content of the coal nor of its size distribution. It appeared that friability and inherent moisture content of the coal may have affected particulate loadings since those properties are influenced by the amount of fines generated.

POM loadings were dramatically lower than those reported in an earlier report for intermittent operation. Particle size distribution was primarily between 15 and 30 micrometers.

The limestone/coal fuel pellet with a calcium/sulfur molar ratio of 7 reduced SO_2 emissions by over 70%. Even at elevated bed temperatures greater than 1100 C, calcium reacted with the sulfur and retained it as a sulfide sulfate complex as part of the fuel ash. CO levels generally ran between 50 and 100 ppm. The use of the coal/limestone pellet tended to flux the ash, causing clinkering and non-uniform bed burning and increasing CO levels to as much as 290 ppm. In a spreader stoker running on limestone/coal pellets, bed temperatures were noticeably lower than for coal alone. Generally the bed temperature was less than 1000 C and this resulted in higher CO emission rates.

Critical Comments. The principal observation is the increase of CO emissions in the limestone/coal pellets, which would indicate the need for increased volatiles content in the pellet in order to produce a hotter burning fuel that was consumed somewhat more rapidly than the coal/limestone mixture. Additionally, the inclusion of limestone would tend to suppress other acid gases that might be produced by components in the refuse as well as reduce sulfur emissions. The combined effect would be of great importance in reducing the potential for boiler corrosion due to the presence of polyvinyl plastics, etc. in the refuse component. Also, the lower fuel bed temperatures should be noted.

Phase II - Control Technology Evaluation

Summary. In this portion of the project, a larger 25,000 pounds per hour spreader stoker/boiler was used for testing prepared coal and other high sulfur content fuels. The summary results were: the limestone/high sulfur coal pellet showed a sulfur capture of about 75% with a calcium sulfur molar ratio of 7. High excess air rates and overfire air proportion at low loads resulted in increased sulfur retention in the bed ash. CO and smoke levels were controlled by providing adequate excess air. CO levels were low for all fuels tested except the limestone/coal pellet. Clinker formation may be a limiting factor in determining the minimum excess air rate. Clinker formation occurred readily if the bed depths were excessive, with 6.3 to 7.6 cm bed depths reported as optimum. High sulfur Ohio coals had to be fired with higher excess air ratios than did the low Ohio and Kentucky coals.

Critical Comments. The principal result of this section of the report appeared to be a reacquaintance with the operating principals of spreader stokers. Data produced was predictable, based on historical operations of spreader stokers, except the change in overfire/underfire air ratios.

Phase III - Limestone/Coal Pellet Development

Summary. This first portion of the program had four principal goals. The first goal was to develop a pellet which was suitable in mechanical strength to withstand both weathering and the stresses of industrial stoker coal handling. Further, it should capture sufficient sulfur to be competitive with other sulfur control strategies. The second goal was to process variables selected to carry out a series of experimental studies in order to provide a comprehensive understanding of the processes that influence the combustion of the pellet and the capture of the sulfur. Third, laboratory evaluations were to be carried out on the pellets to evaluate the most promising pellet. Fourth, an economic analysis was to be prepared to develop the pellet process cost on a reasonable scale. As a result, a pellet was produced that, according to laboratory tests, had sufficient mechanical strength and durability characteristics to be similar to those of conventional coals. In general, pellets produced by auger extrusion or pellet mill processes were stronger than those produced by disc pelleting or briquetting. Binders that provided some resistance to weathering were identified; however, no binder was identified as completely weatherproof. Fixed bed reactor experiments indicated a weak dependency between the calcium/sulfur ratio and sulfur capture for ratios above two. Calcium oxide was shown to be a superior absorbent to limestone, but was *not* economically competitive with the limestone. Results of process variables studies indicated that sulfur is retained predominantly as calcium sulfate. Apparent reactions between the sulfur and limestone were solid state processes without the intermediate formation of SO_2. In the laboratory evaluations, again the denser or auger extruded and pelleted pellets burned better than the briquettes and disc agglomerated pellets. Sulfur capture was about 65% at calcium sulfur molar ratios of 3.5. Sulfur capture in the steam plant was lower (about 50%) and this was attributed to higher burning temperatures(i.e., in excess of 1300° C). Sulfur capture appeared to be weakly dependent on fuel bed temperatures. Fuel pellets burned as well as low sulfur coal. The results of the economic analysis were to produce pellets for a cost of approximately $14 per ton above the cost of the base fuel (i.e., high sulfur coal). This result was based on a 60 ton per hour facility. For cost purposes, pellet composition was assumed to be 65% high sulfur coal, 32% limestone, 2% pre-gelatinized cornstarch and 1% latex emulsion.

Critical Comments. The principal value in this section of the report was the extensive list of binders evaluated in terms of prognosticating their utility for pellet formation. Approximately 80 binders were investigated and a number showed considerable promise. A binder which shows improved characteristics beyond those tested has been identified, but this information was not released by Battelle since they seek a proprietary position in the binder. Secondly, other work by Battelle and reports on fireside metal wastage from firing refuse and refuse and coal combinations have indicated a certain suppression of sulfur emissions from the coal by the presence of refuse. Intimate blending of refuse could reduce the requirements for limestone and would tend to also reduce the sulfur content, suggesting that a combined pellet would improve the combustion characteristics as well as suppress sulfur oxide emissions from the coal without a dramatic increase in ash content. A test of this hypothesis is extremely important as it promises to produce a way to burn refuse satisfactorily, even refuse whose ash content is higher than desirable, while also providing a market for high sulfur coals.

A FIELD TEST USING COAL/dRDF BLENDS IN SPREADER STOKER FIRED BOILERS

Performing Organization: Systems Technology Corporation

Sponsor: Solid and Hazardous Waste Research Division, Municipal and Environmental Research Laboratory, Cincinnati, Ohio 45268

Contract No. [illegible]

Summary

This report [illegible] major controlled testing of dRDF [illegible]. The program [illegible] three principal questions.

1. Can dRDF be burned within existing environmental constraints?

2. Does dRDF burning have any detrimental effects on boiler systems?

3. Is dRDF an economical substitute for coal?

The program included the preparation of approximately 300 tons of dRDF by the National Center for Resource Recovery in Washington, D.C. During production, the economics of the dRDF production were to be evaluated. NCRR's report has been reviewed in a different brief. Boiler performance tests were carried out near the fuel production site at heating plant boilers owned by the Maryland Correctional Institute. These were the spreader stoker vibrating grate type. A temporary alternate fuel feeding system was constructed in order to control the preparation of fuel mixes and to monitor very carefully the amount of fuel used during the test. In addition, the secondary fuel system was to guarantee that the boiler plant would not be placed out of commission due to unforeseen difficulties with the pelletized fuel. The results of the performance tests were not terribly surprising. The pelletized fuel burned readily with several different types and grades of coal and produced steam at the desired rates. Steam load rates on the boilers were generally found to be low due to the nature of the source of load, i.e., multi-building heating and food preparation. Most of the results were predictable, if one carefully considered the properties of the fuels that were being fired. Minimal fouling of the walls was observed and corrosion specimens were [illegible] and [illegible]; minimal corrosion was noted with the exception of a single specimen that was under a point where slagging occurred because of a maladjusted spreader. When the spreader adjustment was corrected, the slagging disappeared. The bottom ash was generally finer as dRDF was substituted for coal in the facility. Similarly, ash collected by electrostatic precipitators and normal mechanical dust collectors was generally skewed toward a smaller particle size range. Carbon content of the fly ash captured by emission control equipment was very high, but decreased as dRDF was substituted for the coal. Generally, the boiler efficiency was low, about 55% to 60%. Maximum efficiency measured on the test boiler was 79% at an excess air rate of 34% when the boilers were new. The boilers were operated for most of the test period at approximately 30% of design rating and at very high excess air rates.

In terms of environmental performance, particulate emissions generally were somewhat decreased due to improved burn-out of the carbon in the particulate. Particle resistivity was increased relative to that of coal alone. Electrostatic precipitator performance was not measured, although a test was attempted. Opacity generally decreased as dRDF was substituted for coal. Sulfur dioxide decreased in direct proportion to the rate of dRDF substitution. Nitrogen oxide measurements showed no significant differences. Chlorine and florine emissions increased. Hydrocarbons stayed approximately the same, at a very low level. Several trace metal emission rates increased significantly but not to a level of concern.

The fuel handling system performed reasonably well. Some information was obtained about fuel storage and it was noted that, when exposed to the elements, the fuel degraded rapidly and severely. Hence, covered storage appeared to be a requirement for dRDF.

Critical Comments

In general the program accomplished the goals that it set out to achieve, i.e., to demonstrate on a preliminary basis that dRDF could be cofired with coal without prohibitive detrimental effects. Difficulties with dusting of the fuel were recognized in the preliminary work. Additionally, fuel quality was and has continued to be less than totally desirable. Further, the economics of the dRDF production system still remain obscure.

COAL/dRDF DEMONSTRATION TEST IN AN INDUSTRIAL SPREADER STOKER [illegible]

Performing Organization: Systems Technology Corporation

Sponsor: Solid [illegible] Research Division, Municipal Environmental Research Laboratory, Cincinnati, Ohio 45268

Contract No. [illegible]

Summary

This study [illegible] investigations carried out at the Maryland Correctional [illegible] consisted of a burn period of a total of 40? hours on dRDF during which approximately 1,700 tons of dRDF were cofired with coal in volumetric ratios up to 4 to 1, and one brief period where dRDF [illegible] fired. Substantial portions of the fuel had been stored out-of-doors for more than six months and were severely degraded in nature, being predominantly moist fines.

Results. No great surprises were discovered during the tests in terms of boiler performance or changes in environmental impacts of the boiler. Sulfur emissions were reduced in direct proportion to the dRDF substituted for the coal. Certain heavy metals, including lead, were up as dRDF was substituted. A slight drop in boiler efficiency was noted; however, this was accredited to the high moisture content of the pellets. The moisture content was considerably higher after storage, [illegible] generation of the fines than when the pellets were first manufactured. Dust generation was noted as severe where the pellets were unloaded from trucks and at conveyor transfer points. Pellet ash contents ranged from as low as 14% to over 30%. Moisture contents ranged from 14% to 34%. Some clinkering was noted with the high ash pellets that had been stored for a long period of time and, thus, were fired as mostly fines. This may have been a function of the ash content of the pellets or the blinding effect of excess fines on the fuel bed which tended to cause unequal air distribution. Lower ash content and less degraded pellets did not show the clinkering effect. Pellets that were deteriorated caused considerable materials handling problems and required constant manual rodding of the fuel bunker in order to remove various fuel blends from the bunker and distribute them to the boiler feeders.

Emissions from the materials were as expected: substantially increased chloride due to the increased chloride content of the refuse, decreased SO_2, significant increases in metals, and no effect on NO_x,

CO or hydrocarbons. Fly ash particle size distribution range changes went in both directions depending on the condition of the pellet being fired. Corrosion measurements were attempted, but no evidence was detected that corrosion would be a problem.

Critical Comments

Two areas of the test were somewhat deficient. The first of these was the system used for metering the blend of dRDF and coal which was adjusted on moisture contents determined on the as-received fuel. After storage, the moisture content of the pellets had increased substantially. This caused a general error in the cofiring measurements so that substantially less dRDF was fired than planned.

A second area of considerable experimentation difficulty was the variability of the boiler load. The boiler being used for tests was the boiler used exclusively to follow load variations. This gave rather dramatic and almost continuous shifts in the load rating of plus or minus 15% to 25% over a given average loading, making precise data interpretation extremely difficult.

Interestingly, in spite of many difficulties, no derating of the boiler was required even at full load or more. Boiler efficiency was reported to be down by a few percent and might well have been adjusted by improved air handling or improved instrumentation to follow load in a more anticipatory manner. Overall, the test demonstrated dRDF could be successfully utilized as a boiler fuel with certain physical handling difficulties. Pellet integrity left much to be desired as did the heat content. The quality of the fuel could be considered acceptable, although not necessarily desirable. The same conclusions are being drawn at Wright-Patterson Air Force Base.

WASTE TO ENERGY COMPENDIUM

Performing Organization: National Center for Resource Recovery, Inc., Washington, D.C. 20036

Sponsor: U.S. Department of Energy, Assistant Secretary for Conservation and Renewable Energy, Office of Energy from Municipal Waste, Washington, D.C. 20585

Contract No. AC01-76DS20167

Summary

The document describes 35 waste to energy projects in the United States. Included in these are nine refuse-derived fuel production facilities, six refuse-derived fuel user facilities, two combined production and user facilities, and 18 mass burning facilities. Only those facilities that are operational or in advanced stages of startup have been included in this survey. Only one dRDF user is reported.

Conclusions

Based on the survey presented, the only dRDF user presently active in the United States on a significant basis is the U.S. Air Force at Wright-Patterson Air Force Base.

Critical Comments

The document provides an excellent overview of the status of the industry as of April 1981. In general, one can conclude that, if dRDF is to be a viable energy resource in the United States, it must succeed or fail at Wright-Patterson Air Force Base.

EVALUATION OF THE AMES SOLID WASTE RECOVERY SYSTEM: REFUSE PROCESSING PLANT AND SUSPENSION FIRED STEAM GENERATORS

Performing Organization: Midwest Research Institute

Sponsor: City of Ames, Iowa, Department of Public Works; and Industrial Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268

Summary

The City of Ames, Iowa, constructed a refuse-derived fuel manufacturing system in the mid-1970's. Initial operation was plagued with a number of difficulties including excessive ash content in the fuel product, which contributed to unacceptable rates of wear on pneumatic conveyors and other equipment. In addition, there were unacceptable rates of dust generation which contributed to the premature failure of a number of pieces of electrical equipment. During the period 1976 to 1979, modifications were made in the plant design and equipment to reduce the ash content of the fuel and increase the reliability and longevity of the plant. Major improvements to the firing system included: the addition of dump grates to the suspension fired steam generator to improve the completeness of combustion of RDF and a relocation of the RDF fuel nozzles to below the coal nozzles to reduce emissions. A grit removal system in the form of disc screens was added to the processing plant to improve the quality of RDF. Dust controls were added to improve the quality of RDF and to preserve mechanical equipment in the plant, as well as improving the worker environment. Pneumatic conveyor capacity was increased for delivery of the RDF to the fuel user. An experimental investigation of the application of RDF to two stoker fired boilers was also carried out.

Results. During the period of investigation and modifications ash content of the RDF was reduced from approximately 20% to approximately 10%, while the heating value was increased by approximately 25%. During RDF suspension firing, boiler efficiency decreased 3.3% when operating at 80% load and 20% RDF heat substitution rate. Efficiency decreased 1% at 100% load with 20% RDF heat input. Particulate emissions increased slightly in the suspension fired system, whereas they were decreased in spreader stoker firing of the RDF when compared with coal alone. Oxides of nitrogen and oxides of sulfur both decreased during RDF burning, while chlorides increased. Increased emissions of trace elements, such as zinc, copper, lead and galium were measured, which corresponded directly to increases in the substitution of RDF for coal. Corrosion and metal tube wastage were investigated. No

corrosion or metal tube wastage was observed during the period of the test.

Critical Comments

The report covers an extended period of time during which many plant modifications were undertaken in order to improve operations and the quality of the product prepared. One would deduce that, with continued efforts, further fuel quality improvements might be achieved, although they might not be as dramatic as those achieved during the three years which were covered by this report. Very useful information is offered by the report on techniques for improving the quality of RDF, as well as insights into the costs of produci RDF using the large primary shredder approach. One would suspect if pre-shredding material to relatively fine sizes were feasible in creating a material of 10% ash content, then pre-separation of the material before shredding, or with very minimal shredding to accommodate the separation, could result in further lowering of ash contents of the refuse-derived fuel.

FIELD TEST OF INDUSTRIAL STOKER COAL FIRED BOILERS FOR EMISSIONS CONTROL AND EFFICIENCY IMPROVEMENT, SITE B

Performing Organization: KVB, Inc., Minneapolis, Minn. 55442

Sponsors: U.S. Department of Energy, Division of Power Systems, Energy Technology Branch, Washington, D.C.
U.S. Environmental Protection Agency, Office of Research and Development, Industrial and Environmental Research Laboratory, Research Triangle Park, North Carolina 27711

DOE Contract No. EF-77-C-01-2609

Summary

The Department of Energy and the Environmental Protection Agency, through a cooperative agreement, funded a major study by ABMA (American Boiler Manufacturers Association) to investigate a number of spreader stoker installations around the country operating on a variety of coals both for boiler efficiency and emissions control capabilities. This particulare site is typical and consisted of a single pass Riley boiler with a Riley spreader stoker, having a continuous rating of 200,000 pounds per hour of steam. During the test, the boiler was operated at 185 psi and 500^{o} F steam, with 225^{o} feed water, even though it was designed to produce 750^{o} steam. Thus, the boiler was somewhat overdesigned for its operation.

Results. During the testing, it was learned that particulate emissions were reduced approximately 25% when the rear boiler wall overfire air flow was increased by 28%. Boiler efficiency was increased approximately 3% by this same overfire air flow modification. The overfire air accounted for 20% to 30% of the total air introduced to the furnace at both intermediate and high loads. When fly ash injection was reduced 30% for a high load test, particulate emissions at the boiler outlet were reduced by 39%. Simultaneously, boiler efficiency was reduced by 2.2%. Of this total loss, 1.3% or approximately half was represented by the heating value of the fly ash that was not reinjected. Particulate loading was observed to increase with the grate or underfire air velocity. Particulate loading appeared to increase at a rate of about 8% for each 10% increase in boiler load over the range tested. Nitrogen oxide emissions did not change substantially. Carbon monoxide emissions were negligible. Boiler efficiency was independent of load, but increased with decreasing excess air at a rate of about .6% for each 1% of O_2 reduction. Among the four different coals tested, no particulate emission relationship was observed because all were similar in size range and basic composition. Similar results were observed for nitrogen oxide and carbon monoxide

emissions, as well as for boiler efficiency changes. Multi-clone and ESP efficiencies approximated 99.8%.

Critical Comments

Significant data were generated to describe spreader stoker boilers firing a variety of coals. While all of this data may not necessarily be translatable to dRDF firing, it certainly does provide leading insights on approaches to improved boiler performance and efficiency. A finding of importance is the direct correlation between boiler efficiency, emissions, and reduced underfire air. A decrease in underfire air at Wright-Patterson Air Force Base, along with improved controls, would reduce the need for fly ash reinjection to maintain efficiency and, thus, reduce particulate loading on the collection system, again without sacrificing boiler efficiency.

TECHNICAL REPORT CONCERNING DENSIFICATION AND GASIFICATION OF REFUSE-DERIVED FUEL

Performing Organization: SPM Group, Inc., Englewood, Colorado

Sponsor: Colorado Correctional Industries, State of Colorado

State Contract No. 650011

Summary

This report detailed experiences in preparing densified refuse-derived fuel using the SPM Group process and densification scheme for preparing the fuel and then for gasifying the fuel in a Forest Products, Inc. close-coupled gas generator and firing the gases in a small boiler.

Results. The results from the test suggest that no major problems were encountered in the production of the briquettes required for the test, i.e., several hundred pounds. The fuel had a heating value of 7,500 BTU's per pound and an ash content of 8%. Gasification of the briquettes was successfully carried out on the pilot scale investigation and appeared capable of being scaled up.

Critical Comments

This report is presently the only one available on the SPM Group densified refuse-derived fuel preparation system. It implies that the system performed its functions satisfactorily in every sense of the word. However, the scale of operations was relatively limited as was the duration of the tests. Scale-up problems and reliability problems could be realized if the system were expanded and if operating demands were increased.

DESIGN CONSIDERATIONS FOR MUNICIPAL SOLID WASTE CONVEYORS

Performing Organization: National Center for Resource Recovery, Washington, D.C.

Sponsors: U.S. Environmental Protection Agency, Municipal and Environmental Research Laboratory, Grant No. R80679091; and U.S. Air Force Engineering and Services Laboratory, Tyndall Air Force Base, Florida

Summary

The purpose of the research was to develop a systematic comparative evaluation technique that would apply to the design of conveyors for municipal solid waste and its derivatives. Two types of conveyors were tested; belt conveyors of varying inclination and idler angle, and vibrating pan conveyors. The report included a discussion of the various materials and operational parameters as developed by Conveyor Equipment Manufacturers Association and their application to municipal solid waste and its derivatives. Tests were carried out to evaluate spillage against conveying capacity. A majority of the work was done on belt conveyors.

Results. In general, the results indicated that significant losses could be expected with any type of conveying system tested within the range of conditions and parameters tested.

Perhaps the most significant conclusion was that considerably more engineering evaluation was required in order to develop a conveyor design technique for municipal solid waste and its derivatives. Useful significant data in both the area of belt velocity and loading capacity was presented on a comparative basis. However, one chart demonstrated that even at the minimum feed rate and conveying rate on a belt conveyor with municipal waste, spillage was on the rate of .05% per hour per 25 foot length. The conveyor was rated at five tons per hour. Thus, in a 24 hour period of operations, six tons of material would be lost.

Critical Comments

The work is of considerable value as a first step in evaluating municipal solid waste conveyors. In general, one might conclude that they have been dramatically undersized, given the properties of the material that they are designed to convey. Alternatively, a broader spectrum of conveying capabilities should have been examined for those which were most compatible with the varied properties of municipal solid waste. No attempt was made to segregate the solid waste materials by screening in order to determine the relative contribution of their various size fractions of solid waste to the spillage problem. For example, the dynamics of conveying, as well as wind resistance, create a situation such as is found in an air classifier; i.e., the fines will tend to be scrubbed from the moving conveyor if they are even minimally exposed to air resistance. A significant portion of the spillage consisted of fines which are reported as present in large quantities in most solid waste systems. A comparative definition of acceptable spillage rate against cost of cleanup might be very useful in order to determine the level at which a conveyor design is monetarily acceptable. A scan of conveying technologies for compatibility with municipal solid waste would be most useful as compared to their application for other materials (i.e., definition of solid waste properties for conveying purposes and comparison with properties and the types of conveyors and sizes which have been used). Such an empirical approach could provide much useful data for future research work.

DENSIFICATION OF REFUSE-DERIVED FUELS: PREPARATION PROPERTIES AND SYSTEMS FOR SMALL COMMUNITIES

Performing Organization: National Center for Resource Recovery, Washington, D.C. 20036

Sponsor: Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268

Grant No. 804150

Summary

The objective of this work was to investigate and describe the operation, performance and production characteristics of a shredder and densifier subsystem which was to produce densified refuse-derived fuel from shredded, air classified, magnetically separated municipal refuse. The RDF preparation process consisted of: feed conveyors and a 100 ton per hour shredder, 20 ton per hour outfeed conveyors, magnetic separator, aluminum separator, and an air classifier. A pre-trommel was used during portions of the test program. The prepared light fraction was secondary shredded, air classified again and delivered to a densifier. The densifier subsystem consisted of a live bottom bin which fed a California Pelletmill. The pelletizer was operated mainly with half inch opening dies and produced pellets at a maximum rate of two to three tons per hour of operation.

[illegible] primary system, [illegible] was of much larger capacity than the pellet production system, had significant adverse influence on the operation and reliability of the densifier subsystem. The secondary shredder was initially operated with thirty-four 1 1/2 in. thick hammers and was altered to accommodate 72 smaller hammers. The shredder, however, failed to reliably reduce the size of textiles in the system, which in turn created significant problems in the operation of the pelletizer. In general, however, one might conclude that the shredder did not perform satisfactorily as a feed device for the pelletizer subsystem. Knife hammers seem to have performed the most satisfactorily, of the hammers tested, for shredding of air classified light fraction.

Densifier operations were monitored throughout testing. A predicted 8 to 10 tons per hour [illegible] was never realized. The apparent reasons for this were: (1) the equipment configuration, (2) the die and roller condition, (3) stability of feed rate, (4) general feedstock properties including moisture, density and particle size, and the presence of oversized textiles. New rolls were

substituted during the operation of the mill which temporarily increased the rate of throughput from 2.3 tons per hour to 3.5 tons per hour. The increase was thought to be due to sharper nipping of the material by the corrugated rolls, which implies that if the material had been further reduced in size by preshredding, throughput from the mill might have increased dramatically. Loss of sharp edges in the new rolls occurred with less than 50 tons of throughput and capacity dropped. Consequently, the rolls would have to be renewed repeatedly or the feed material modified in such a way that shearing was not required of the machine. Die and roller life was projected at 2,313 tons for dies and 1,211 tons for rollers. If the ash content of the feedstock were reduced from 25% to 10%, this life could be doubled to 3,550 tons. This increased die and roller life was used to estimate the economic viability of the process, not the life actually measured in pilot operations.

Pellets prepared from the light fraction with greater than 30% moisture content tended to be scaly and break apart readily, producing a large quantity of fines. A correlation between pellet density and fines content was attempted. Fines concentrations of up to 25% were measured after 10 drops of the pellets in an empirical test procedure.

While the pellets were stored outdoors, some oxidation was observed in the form of smoldering seams. These seams had to be excavated and quenched with water. Five hundred tons of pellets produced were thus lost. Additionally, the cause of the oxidation was never defined. Both extraneous sources of fire, such as cigarettes tossed into the pile, and spontaneous combustion are possible sources. Aerated covered storage is suggested as the best method for storing dRDF in order to promote drying and prevent the addition of moisture either from the elements or manmade sources.

The economics of the densification process and prior processing was predicted on the basis of allowable sales price of the fuel product estimated at two levels, $1.50 per million BTU's and $2.50 per million BTU's. Under these conditions and with the other optimistic assumptions of equipment life, two sizes of plants were described as economically feasible. Conclusions concerning the economics of the process are difficult to evaluate. Total cost of a small facility (i.e., 10 tons per hour capability) is prognosticated at $1,687,000 for the front end system and an additional $390,000 for the densification module. It should be noted, however, that these throughput levels of 20 and 10 tons per hour are very optimistic since only one or two densifiers are included and actual performance has been two and a half tons per hour per densifier, not 8 to 10. The overall capital cost of the small dRDF facility of $1,687,000 appears quite reasonable overall. The actual productive capacity of such a plant must remain a point of speculation, since to date no one has been able to operate pellet mills at a reasonable rate of pelletization which would allow for adequate repayment of investment. (Routine operation of these pellet mills by the MES contractor has demonstrated an average capacity of 1 1/2 tons per hour per pellet mill.)

Critical Comments

Work carried out by the National Center for Resource Recovery offers much enlightenment concerning advantages and disadvantages of attempting to create a densified refuse derived fuel for use in commercial boilers. Much of the data and the difficult experiences which NCRR recorded will be of great benefit to second and the third generation attempts in this area.

The approach to the definition of the economics of dRDF is not as useful as other approaches might have been. The reader is left in doubt as to whether dRDF is an economically viable or inviable process. Certain of the caveats, such as the extension of production capacity for densifiers far beyond that which was demonstrated in the field, make the economics of the process as displayed in the report highly questionable. The report provides many insights into problems that other researchers and commercial ventures in the densified fuels area would like to bypass. Careful study of this report is therefore warranted.

EVALUATION OF dRDF USED AT MILITARY INSTALLATIONS

Performing Organization: Cal Recovery Systems, Inc., Richmond, California

Sponsor: Department of the Navy, Civil Engineering Laboratory, Port Hueneme, California

Contract No.

Summary

The purpose of this work was to assess the specifications currently being used for dRDF, establish the similarities and differences between fuels that might be fired in a spreader stoker, and assess current production and firing techniques for dRDF. Recommendations are offered for an improved set of dRDF specifications and additional research concerning the production of dRDF at existing pilot plants.

Results. Pellet drying and cooling is recommended in order to reduce degradation through biological means. Pellet densities of 65 to 70 pounds per cubic foot and moisture contents of 15% are described as routinely achievable.

Critical Comments

The report provides valuable data concerning specifications for dRDF. The research suggested in terms of dRDF production appears to be add-ons to existing systems and not particularly directed toward fundamental problems affecting the quality of dRDF. The properties suggested (i.e., 65 to 70 pounds per cubic foot) must be assumed to address density of an individual pellet and not bulk densities of pellets as delivered. Bulk densities of pellets as delivered would probably never exceed 35 pounds per cubic foot and this would only be achieved at a bulk density on an individual pellet basis at 70 pounds per cubic foot. Voids are created in a pile of pellets of uniform size. Screened, washed coal produces densities of only about 50 pounds per cubic foot as delivered and this includes a broad spectrum of particle sizes. Given the results achieved to date by existing producers of dRDF, the specifications described in the document seem extraordinarily optimistic.

FUNDAMENTAL CONSIDERATIONS FOR PREPARING DENSIFIED REFUSE-DERIVED FUEL

Performing Organization: University of California, Department of Mechanical Engineering, Berkeley, California 94607

Sponsor: Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, [illegible] 45268

Grant No. R-[illegible]-01

Summary

A series of pilot and bench scale tests were carried out to examine the effects of various parameters on the densification of refuse-derived fuel. Experiments on a single die, as well as experiments which incorporated a commercial pellet mill, were described. Background information concerning data developed by the agricultural industry pertaining to animal feed pelletization was also incorporated in the report. Relationships were developed which describe the specific energy of densification and mass flow through a mill. Data were also developed that related the effect of feed moisture content on pellet density and feed particle size on pellet production rates.

Results. Several interesting conclusions were offered. One was the enormous increase in energy required for pelletization if the thickness of the load of feedstock around the surface of the die was less than one half the size of the opening through which the material was to be forced. Another was the dramatic increase in power required if feed size is larger than the opening through which the material must be forced. Perhaps the most interesting conclusion offered was the effect of inlet taper on the die with the die having the greatest taper requiring the least amount of energy. This suggests that far more work is consumed by compression and compaction of material than this study would appear to suggest in specific single die experiments.

Critical Comments

The study offered much valuable data concerning the energy and work required for forming pellets from refuse-derived feedstocks. Additional cost correlations between the characteristics of material routinely pelletized, i.e., feed materials for the agricultural industry, and the characteristics of refuse would have been extremely beneficial. Additional experiments concerning the total work required for compacting material, i.e., precompacted refuse, should have been included in the experimental program so that only work required for deformation and extrusion could have been measured. Upon viewing the structure and mechanics of pellet mills, one concludes that these devices are designed primarily to extrude finely divided materials. They are not designed to be efficient precompaction devices in order to raise the bulk density of material by an order of magnitude prior to extrusion. Such an experiment would be extremely useful in determining the role of pellet mills in the preparation of densified refuse-derived fuel.

USE OF WASTE OILS TO IMPROVE DENSIFIED REFUSE-DERIVED FUELS

Performing Organization: National Center for Resource Recovery

Sponsor: U.S. Department of Energy, Assistant Secretary for Conservation and Solar Energy, Office of Buildings and Community Systems

Contract No. [illegible]

[illegible]

The purpose of the experimental program was to test the hypothesis that the addition of waste oil [illegible] to the dRDF production process would lower production costs by reducing friction during passage of the refuse through the die and increase the storability of the dRDF because of the hydrophobic properties of the oil included in the dRDF.

Results. [illegible] was added during the production process to certain maximum amounts. These amounts were determined by the prediction that lead emitted from the combustion of the pellet would be the limiting factor. Thus, a maximum of 15% oil by weight was defined as an upper limit. The oil was blended in the refuse prior to the pelletization operation and pelletization tests were run at several levels. In general, the higher the level of oil, the less dense and less cohesive the pellet. In terms of achieving better storage because of the lowered pellet density and cohesiveness, water adsorption was increased, not decreased, by the addition of oil. This result was explained by the observation that the lower density pellets easily broke apart and this exposed greater surface area to potential moisture sources.

Critical Comments

The addition of oil during the production process is one approach to the production of more waterproof dRDF pellets; however, oil is a non-polymerized material. Use of waste oil in the pelletizing process does little to create the polymerization of the molecules and increase the cohesiveness of the pellet. The research carried out should have been followed by some type of polymerization treatment on the pellets. One such process might have been the irradiation of pellets with electron beams to cross link the oil molecules with other parts of the pellet.

The inclusion of oil in the production process should have been identified as likely to lead to negative results. Oil is basically a lubricant; hence, one would suspect that it would reduce the cohesiveness of the pellets, not increase it, as experimental results confirmed. No tests were run using oil as a surface coating; that is, oil could be sprayed on the pellets after the pellets were formed and cooled or during the cooling process, creating a hydrophobic barrier at the surface of the pellet without perceptibly increasing the oil content of the refuse. Additional coating materials, such as paraffin, denser grades of fuel oil, etc. should be examined on an experimental basis in order to determine whether a surface coating could have improved pellet resistance to moisture absorption as well as increased pellet stability.

STUDY ON THE STATE OF THE ART OF DIOXIN FROM COMBUSTION SOURCES

Performing Organization: Arthur D. Little, Inc.

Sponsor: Research Committee on Industrial and Municipal Wastes, American Society of Mechanical Engineers

Summary

The purpose of this work was to examine the overall problem of dioxins created by the combustion of municipal wastes. The study examined the basic chemistry of dioxin, including procedures for detecting dioxins in flue gases and ash, and assessed the hazard that might be created by the release of these levels of dioxins.

Results. Conclusions were offered that indicated that the level of risk from the release of dioxins through combustion sources was extraordinarily low, much lower than many normal risks encountered by the general population in many unrelated activities. This risk was justified in view of the need to satisfactorily dispose of the waste generated by the population.

Critical Comments

In view of the minescule dioxin levels which have been measured and the total lack of data indicating any negative effects on the general population, the uncertainty seems to have been satisfied. One would assume that, since waste has been incinerated for many years and no epidemiological effect on any population in many different areas of the world has ever been documented, the practice is safe.

NUMERICAL SIMULATION OF COMBUSTION AND GASIFICATION OF WET CARBON AND WET SLUDGE UNDER EQUILIBRIUM AND ADIABATIC CONDITIONS

Performing Organization: Systems and Economic Analysis Section, Ultimate Disposal Section, Treatment Processes Development Branch

Sponsor: U.S. Environmental Protection Agency, Municipal and Environmental Research Laboratory, Ultimate Disposal Section, Treatment Processes Branch (Unpublished Report)

Summary

The purpose of this work is to develop numerical simulation techniques to estimate the impact of water on the combustion of carbon as this might apply to sewage sludge being burned in a multiple hearth incinerator under reducing conditions. The approach is relatively straightforward and duplicates, to a large degree, work on other types of fuels burned under the same conditions.

Critical Comments

This work is of significance when considering the cofiring of coal and dRDF because it impacts on the effect of the moisture content of the dRDF and the fuel bed. *Two salient* facts are brought forth in the work.

First, approximately 80% of the heat content of the sludge or carbon source is retained in the product gases produced by burning solid fuel in a starved air condition. As a result, the temperature of the burning bed is substantially lower when relatively wet sludge is burned than if the sludge were pre-dried. This is of significant importance in the cofiring of dRDF and coal because it indicates that fuel bed temperature and clinkering (which is a result of excessive bed temperatures) or low ash softening points (due to the constituents of the fuel bed) may be controlled by the presence of moisture as opposed to the use of excessive underfire air. Excessive underfire, in turn, creates additional burden on the electrostatic precipitators or pollution control equipment and increases the potential for slagging and deposition on the boiler tubes.

Second, for completely dry, volatile solids or carbon, 1.17 moles of molecular oxygen are required for combustion. In the presence of moisture, however, no more than .415 moles of oxygen per mole of carbon, or about 35% of the stoichiometric requirement, is required. The explanation is that the moisture tends to convert the fixed carbon into carbon monoxide under reduced air conditions; the combustible gases may then be burned above the bed in the presence of overfire air. Reduced underfire air to reduce emissions appears feasible due to the presence of moisture in the bed which could be contributed by a relatively wet dRDF pellet. The minimum underfire oxygen required on a mole basis occurs at a moisture to fixed carbon ratio of .45 to 1. This allows for minimum underfire air while obtaining complete combustion in the fuel bed and, at the same time, creating a hot gaseous mixture. The hot gaseous mixture burns rapidly with substantial radiant heat above the fuel bed and with greatly reduced particulate fuel loss. Experimental investigation of this hypothesis is extremely desirable.

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